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A bench scale
evaluation of
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for use in
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Schafer & Associates

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A BENCH SCALE EVALUATION OF ORGANIC SUBSTRATES FOR USE IN CONSTRUCTED WETLANDS FOR THE TREATMENT OF ACID MINE DRAINAGE

Submitted To:

Montana Department of State Lands
Abandoned Mine Reclamation Bureau
Helena, MT 59620

Submitted By:

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Bozeman, MT 59715

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TABLE OF CONTENTS

1.0	INTRODUCTION	1
2.0	OBJECTIVES	1
3.0	MATERIALS AND METHODS	
3.1	Materials	2
3.2	Methods	4
4.0	RESULTS	
4.1	Effluent Analysis	8
4.2	Depth Sampling Chemistry	23
4.3	Lactate Addition	31
4.4	Substrate Metal Fractionation	32
4.5	Substrate Neutralization Potential	37
4.6	Hydraulic Conductivity	39
4.7	Observations	40
5.0	DISCUSSION	42
6.0	CONCLUSIONS	44
7.0	LITERATURE CITED	46
APPENDIX A	COLUMN INFLUENT AND EFFLUENT CHEMISTRY	
APPENDIX B	MUSHROOM COMPOST AVAILABLE	
	PHYSICAL AND CHEMICAL CHARACTERISTICS	
APPENDIX C	COLUMN PORE WATER CHEMISTRY	
APPENDIX D	COLUMN SUBSTRATE METALS	
	FRACTIONATION RESULTS	
APPENDIX E	SUBSTRATE METALS	
	FRACTIONATION METHODS	



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LIST OF TABLES

Table 1.	Mean AMD influent chemistry.	2
Table 2.	Substrate physical and hydraulic characteristics.	3
Table 3.	Substrate pH, neutralization potential and neutralization capacity.	38

LIST OF FIGURES

Figure 1.	Typical column design employed in substrate evaluation column study	5
Figure 2a.	Substrate mean influent and effluent pH and acidity/alkalinity concentrations	10
Figure 2b.	Substrate mean influent and effluent pH, Al and Fe concentrations.	11
Figure 2c.	Substrate mean influent and effluent pH, Mn and Zn concentrations.	12
Figure 3a.	Substrate mean influent and effluent pH and acidity/alkalinity concentrations	14
Figure 3b.	Substrate mean influent and effluent pH, Al and Fe concentrations.	15
Figure 3c.	Substrate mean influent and effluent pH, Mn and Zn concentrations.	16
Figure 4a.	Substrate mean influent and effluent pH and acidity/alkalinity concentrations.	18
Figure 4b.	Substrate mean influent and effluent pH, Al and Fe concentrations.	19
Figure 4c.	Substrate mean influent and effluent pH, Mn and Zn concentrations.	20
Figure 5a.	Substrate pore water Eh, pH, S^{2-} , Al and Fe concentrations by depth.	24
Figure 5b.	Substrate pore water Eh, pH, S^{2-} , Mn and Zn concentrations by depth.	25

Figure 6a.	Substrate pore water Eh, pH, S ²⁻ , Al and Fe concentrations by depth.	26
Figure 6b.	Substrate pore water Eh, pH, S ²⁻ , Mn and Zn concentrations by depth.	27
Figure 7a.	Substrate pore water Eh, pH, S ²⁻ , Al and Fe concentrations by depth.	28
Figure 7b.	Substrate pore water Eh, pH, S ²⁻ , Mn and Zn concentrations by depth.	29
Figure 8.	Percentage of total Al removed for each substrate by sorbed and solid fraction.	33
Figure 9.	Percentage of total Fe removed for each substrate by sorbed and solid fraction.	34
Figure 10.	Percentage of total Zn removed for each substrate by sorbed and solid fraction.	35
Figure 11.	Substrate neutralization potential prior to introduction of AMD.	38
Figure 12.	Substrate saturated hydraulic conductivity values through time during study	40

1.0 INTRODUCTION

Acid mine drainage (AMD) is a potential threat to the surface and groundwater quality of many drainages in central and western Montana. It is present at many abandoned coal and hard rock mines, resulting from the oxidation of pyrite and other sulfides in mine waste rock, tailings and underground workings. Recent research indicates that the use of constructed wetlands can be successful at removing iron (Fe) and other metals and improving the effluent water quality from small (< 20 gpm) AMD flows. Most constructed wetlands have been designed to function as throughflow wetlands, meaning AMD flows over a substrate and metals are removed via oxidation. Often there is very little increase in pH. Conversely, wetlands designed to maximize contact of the AMD with the substrate to optimize microbial sulfate reduction have been observed to produce a notable increase in pH in addition to metal removal. To optimize sulfate reduction, a substrate must provide a readily-metabolized source of organic carbon (C) and adequate nitrogen (N) for the sulfate reducing bacteria. Additionally, the substrate should support the growth of cattails or other aquatic plants and be an integral part of a long-term source of nutrients for the bacteria. Uniform hydraulic conductivity is also a desired attribute in order to prevent short-circuiting of upflow and allow for maximum contact with the substrate.

Schafer and Associates was retained by the Montana Abandoned Mine Reclamation Bureau (AMR) to perform a screening and evaluation of potential substrates for use in constructed wetlands to treat AMD. A bottom-feed column experimental approach was employed using AMD collected from the combined flows of the French Coulee/Anaconda Mine adit discharges in Belt, Montana. Six substrate sources were evaluated including 2 peats from Montana, 2 mixed wood waste/sewage sludge sources and 2 mushroom composts. Influent, effluent and solid substrate analyses were performed to quantify the effectiveness of each substrate. The results from this study will be used to guide further research and in developing a selection for a cost-effective substrate(s) for use in future constructed wetlands.

2.0 OBJECTIVES

The objectives of the study were to:

1. Determine and quantify the ability of several commercially available organic substrates to support sulfate reduction.
2. Quantify the performance of each substrate at improving AMD effluent water quality.
3. Determine the primary biogeochemical mechanisms and location of metal removal in each substrate.
4. Determine and monitor changes in hydraulic conductivity throughout the study.

3.0 MATERIALS AND METHODS

3.1 MATERIALS

3.1.1 Acid Mine Drainage

Acid mine drainage used in the study was collected from the combined discharge of French Coulee and the Anaconda Mine. The collection site is located in the southwest quadrant of the town of Belt, approximately 10 meters upstream of where the AMD discharges into Belt Creek. Effluent was collected in 5 gallon portable jugs and brought back to the lab for use in the columns. Chemical analyses of AMD used in the study are presented in Appendix A. Table 1 summarizes the mean chemistry of the influent AMD.

Table 1. Mean AMD influent chemistry.

Substrate (Column Number)	Al	Fe	Mn	Zn	Acidity as CaCO ₃	SO ₄
	----- mg/l ¹ -----					
(1) Eko-Compost	93.38	100.10	0.21	3.00	1008	1540
(2) Groco	93.01	98.24	0.17	2.89	1012	1480
(3) Great Western Mushroom Compost	92.81	96.46	0.18	2.82	1028	1612
(4) United Foods Mushroom Compost	95.59	95.79	0.20	2.77	1020	1943
(5) Peaco Peat	95.79	100.46	0.20	2.63	1022	1637
(6) Farmers Peat	97.00	96.13	0.21	2.62	1015	1551

¹ - Values after addition of lactate not included in determination of mean.

3.1.2 Substrates

Substrate sources evaluated in the study and their salient physical and hydraulic characteristics are shown in Table 2.

Eko-Compost and Groco are composted woodwaste/sewage sludge products comprised of approximately 80 % and 20% sawdust/woodchips and sewage sludge (dry weight), respectively. Eko Compost is aerobically composted for 2 months, followed by a 2 month anaerobic composting period. Material used in the study was screened to 3/4 inch minus prior to use.

Table 2. Substrate physical and hydraulic characteristics.

Substrate	Bulk Density ¹	Porosity ¹	Liter/Pore Volume ¹	Hydraulic Conductivity ²
	g/cm ³	%	liter	cm/s
Eko-Compost	0.29	78	5.13	1.07x10 ⁻³
Groco	0.20	85	5.59	1.10x10 ⁻³
Great Western Mushroom Compost	0.24	82	5.39	1.60x10 ⁻³
United Foods Mushroom Compost	0.29	78	5.13	1.96x10 ⁻⁴
Peaco Peat	0.19	86	5.65	1.00x10 ⁻³
Farmers Peat	0.34	74	4.87	2.50x10 ⁻⁴

¹ - Determined gravimetrically after compaction of substrate to 4.5 psi.

² - Determined prior to compaction by constant head method.

Great Western and United Foods mushroom composts are spent composted materials used previously for growing mushrooms. Great Western mushroom compost has an N content of 2.1 %. Materials used in the formulation of the mushroom composts are shown in Appendix B.

Farmers peat and Peaco peat are commercially mined peat sources produced near Wisdom and Polson, Montana, respectively. Farmers peat is the sphagnum variety and in general is more fibrous and appears to be less degraded by biological and weathering processes. Available physical and chemical analyses for each substrate are presented in Appendix B. Laboratory analyses performed as part of the study are presented in the Results section.

3.1.3 Column Apparatus

The columns used in the study were constructed of 4 inch O.D. clear acrylic. An influent port, through which AMD could be introduced to the column, was installed at the base of each column. A similar effluent port was located approximately 10 cm above the top of the substrate near the top of the column. Each port consisted of a teflon tubing band threaded into the column sidewall to which a 1/4 inch ID length of tygon tubing was attached. The tubing from the influent port led to a 15 l influent reservoir from which the AMD was fed into the column (Figure 1). A mariotte device to control head delivered to each column was placed in each reservoir. The mariotte device consisted of a rubber 2-hole stopper into which 2 1/4 inch glass tubes were inserted and extended into the bucket. One glass tube was attached to the tygon tubing leading to the influent port while the other was open to the atmosphere. After a siphon was established, the bottom of the open glass tube was at atmospheric pressure and defined the head driving the system. Thus, by moving this tube up or down, the head was adjusted to obtain the desired flow rate. This system also allowed the calculation of hydraulic conductivity, K , by employing Darcy's Law where

$$Q = KA (dx/dy)$$

or

$$K = Q/A(dx/dy)$$

because A is the area of the column and can be measured, dx/dy is constant and can be adjusted and Q can be obtained by measuring discharge from the column over a given increment of time.

Solution sampling ports were also installed in each column at 3, 8, 16, 30, 47 and 77 cm above the base of the substrate. These ports consisted of stainless steel bushings threaded into the sidewall of the column (Figure 1). All threads were teflon sealed. A 3 ml ceramic cup was permanently affixed to the bushings with epoxy and extended into the substrate. A silicon rubber septa was seated between the cup and a nut on the outside of the column which held the port in place and isolated it from the atmosphere.

3.2 METHODS

Eight cm of 1 to 3 inch washed gravel was placed into the base of each column. The gravel extended above the level of the influent port. On top of the gravel was placed a 20 squares per inch plastic screen to prevent piping of the substrate into the gravel. Substrate was added to the column in approximately 30 cm lifts and compacted to 4.5 psi using a wooden dowel with a wooden circle the same diameter as the column I.D. and the appropriate weight. Compaction was performed between each lift to simulate estimated compaction by low ground-pressure equipment during actual wetland construction. A total of 80 cm (compacted) of substrate was added to each column to a depth (prior to swelling) of 15 cm below the effluent port. After swelling, total substrate thickness ranged between 83 and 93 cm.

TYPICAL COLUMN DESIGN

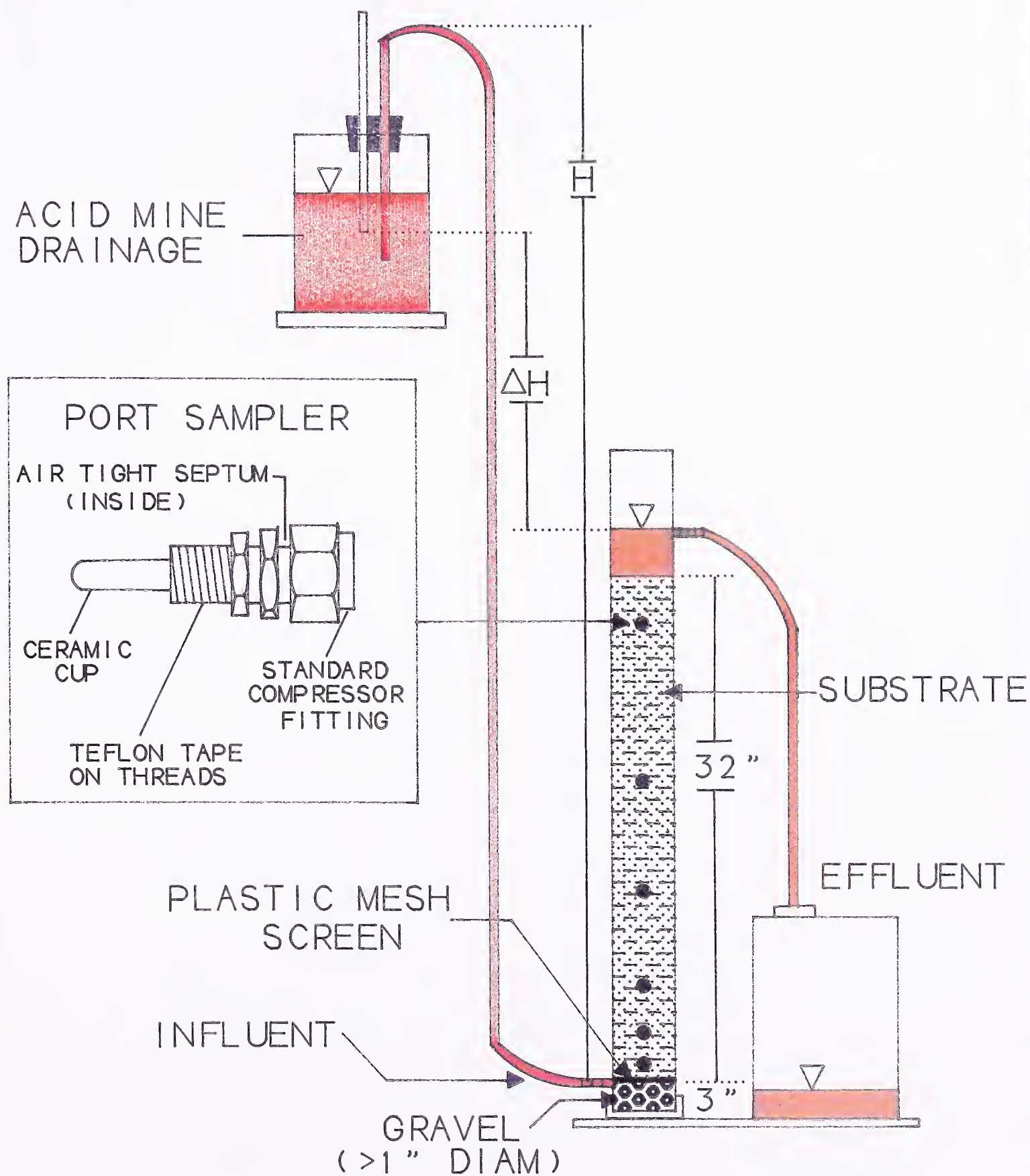


Figure 1. Typical column design employed in substrate evaluation column study.

After substrate was in place, AMD was added to each column to saturate the substrate. This AMD was allowed to remain in the columns for 10 days to establish equilibrium conditions prior to the introduction of any additional AMD. Considerable swelling of substrate also took place during this period. It should also be noted that the columns 3 and 4 were backflushed with air after flow had stagnated. Following backflushing, flow was maintained at head levels that did not move flow prior to flushing.

After 10 days AMD from the influent buckets was introduced to the columns. Initially, the flow was controlled by a stopcock in the influent line and set to a rate of approximately 1 liter/day. However, the constricted aperture of the stopcock prevented the development of sufficient head to maintain this flow rate. As a result, the use of stopcocks was discontinued and flow was controlled wholly by manipulation of the mariotte device after 30 days.

Following depletion of the influent bucket, the bucket was cleaned and filled again with AMD which was then introduced into the column. This cycle was repeated throughout the duration of the study. It should be noted that flow was variable at a given head through time and over short periods of time. Frequent adjustments of the mariotte device were required and flow rate varied both between and within columns, with occasional periods of no flow and rapid flow rates. However, over the 6 month duration of the study, the amount of flow and overall flow rate was similar in all columns and is not considered to be detrimental to the validity of the experimental results.

Each influent was sampled, filtered with a 0.45 micron cellulose nitrate filter and preserved with HCl to pH < 2.0 and analyzed for total dissolved Al, Mn, Zn and Fe using inductively coupled plasma spectrometry (ICP). Periodic analysis of Fe^{2+} and Fe^{3+} were also performed. Ferrous (Fe^{2+}) was determined colorimetrically and Fe^{3+} by difference between total dissolved Fe (ICP) and Fe^{2+} . A second unfiltered sample was also collected and analyzed for SO_4 , acidity, alkalinity, TDS and periodically for total organic carbon (TOC), nitrate N and Total Keldhal N (TKN). Nitrate analysis was performed on effluent through day 160 of the study, after which time TKN analysis was performed due to consistent nitrate N levels below detection in all column effluents. Mean influent chemistry for key analytes are presented in Table 2 in Section 4.0-Results.

Effluent pH, EC and Eh were periodically recorded in the standing water at the top of each column. Effluent samples were collected periodically by placing the effluent tube in a 500 ml polyethylene sample bottle. Samples were preserved in the same way and analyzed for the same parameters as the influent samples. Sodium lactate was added to the *influent* AMD (5 mg/l) for each column at day 209 of the study to determine the effect of a supplemental carbon source on microbial activity.

Two samplings of the ceramic cup sampling ports were also performed. These samples were obtained by inserting a hypodermic needle through the septum and drawing a sample from the ceramic cup. All cups were purged prior to sample collection. Sample pH, Eh and sulfide (S^{2-}) were determined immediately by ejecting the sample into a test tube containing the electrode. Nitrogen (N_2) gas atmosphere was used within the test tubes

to prevent changes in solution chemistry due to oxidation. A double junction Ag-S electrode/KCl reference electrode was used for S^{2-} determination and results were compared to a standard curve developed from reference solutions containing known amounts of S^{2-} ion.

Following the collection of the final effluent samples, solid substrate samples were collected from each column at depths corresponding to the ceramic cup sampling ports. A single sample was collected from the two bottommost port intervals for convenience. All samples were collected while the substrate was still wet (but drained). These samples, and a sample of each substrate not exposed to AMD, were analyzed for soluble, exchangeable, organically bound, carbonate/sulfate, oxide and residual (sulfide) Al, Fe, Mn and Zn fractions using a procedure described by Wieder (1990) and contained in Appendix E.

Inherent substrate neutralization potential was also determined. A 5 gram sample of each substrate was added to 25 ml of distilled/deionized water in a beaker and allowed to equilibrate overnight. Equilibrium pH values were recorded. Each sample was then titrated with 1 N HCl to an end point pH of 2.0. The amount of HCl necessary to decrease the pH to 2.0 was recorded and from this a neutralization potential in $CaCO_3$ equivalents was calculated.

Substrate bulk density (ρ_b) and porosity (n) were determined gravimetrically by drying a known volume of substrate (compacted to 4.5 psi) and employing the following equations, assuming a particle density (ρ_p) of 1.3 g/cm³:

$$\rho_b = \frac{M_s}{V_s} \quad [1]$$

where,

$$\begin{aligned} M_s &= \text{mass of substrate} \\ V_s &= \text{volume of substrate} \end{aligned}$$

and

$$n = 1 - \frac{\rho_b}{\rho_d} \quad [2]$$

These data and other hydraulic characteristics of the substrates are presented in Table 2 if this section.

4.0 RESULTS

Column effluent results will be discussed in detail below by individual substrate (Appendix B). In addition, similarities and differences between substrates will be summarized. Results following the addition of lactate and depth sampling results will be discussed separately, as will be the substrate solid metals fractionation analysis. The relative effectiveness and performance of each substrate and the mechanisms and role of various chemical processes in the performance of each substrate will be addressed in Section 5.0-Discussion. The reader should refer to Table 1 for reference while reviewing Section 4.1.

4.1 EFFLUENT ANALYSIS

4.1.1 Eko-Compost

Effluent water quality showed a marked increase after 1 PV (11 days). Only EC, at 2.90, was slightly higher than the influent value of 2.45, most likely due to the leaching of salts from the substrate. EC levels remained between 1.86 and 2.90 throughout the study. Effluent pH levels increased from an initial value of 5.16 to a maximum of 7.41 after 8 PV, from which point it steadily declined to 3.05 and 3.81 on successive days after 23 PV. Alkalinity decreased from 79 mg/l after 7 PV and became increasingly acidic, reaching a maximum acidity value of 991 mg/l at the end of the study (26 PV) (Figure 2a). An anomalously high titratable acidity value of 6220 mg/l was recorded after 12 PV. Although this corresponds to the first appearance of elevated Fe levels and an increase in Mn concentrations, a corresponding pH value of 6.34 renders this value suspect. Eh exhibited a steady decline from 624 mv to 283 mv after 20 PV and increased again to 535 mv after 23 PV. Values for SO_4 were relatively unchanged versus influent levels throughout the study. Total organic carbon levels (TOC) had a maximum value of 15 mg/l after 7 PV and ranged between 5 and 9 mg/l through 23 PV. Nitrate N levels declined from 0.1 mg/l after 7 PV to below detection limit (0.05 mg/l) through 23 PV. Values for TOC increased to 690 mg/l, after the addition of lactate while Total Kjeldahl Nitrogen (TKN) decreased from 15.2 mg/l to 10.2 after 45 PV.

Effluent Al concentrations were < 0.1 mg/l (detection limit) until 17 PV, at which point the concentration increased to 7.1 mg/l (Figure 2b). After 23 PV the concentration had increased to 82.6 mg/l, reaching a maximum value of 167 mg/l at the time of final sampling (26 PV). The concentration of Fe in the initial effluent (7 PV) was < 0.1 mg/l (Figure 2b). Fe levels exhibited a steady accession in subsequent effluents, from 101 mg/l after 12 PV to 203 mg/l after 17 PV. In both of these analyses, greater than 89 % of the total dissolved Fe was in the Fe^{2+} form, as opposed to > 95 % Fe^{3+} in most influents. By 22 and 23 PV, total Fe had decreased to 138 and 145 mg/l, respectively, with greater than 90% in the Fe^{3+} form in both cases. A final Fe concentration of 83.9 mg/l (80 % Fe^{2+}) was

observed at the end of the study. Concentrations of Mn showed a steady decline from a maximum value of 7.83 after 12 PV to 0.11 mg/l after 26 PV (Figure 2c). Manganese concentrations increased from an initial value of 3.55 mg/l at 3 PV to 7.64 mg/l after 10 PV, exhibiting a decrease in subsequent samples to 0.25 mg/l at 23 PV. The Zn concentration was 0.03 mg/l after 7 PV and was below detection level (0.01) in all subsequent effluents (Figure 2c).

4.1.2 Groco

EC values declined from an initial (<1 PV, 11 days) value of 3.88 to 2.0 at 17 PV. Values for pH remained between 5.93 and 7.13 through the first 7 PV and exhibited a steady decline to 3.26 after 17 PV (Figure 2a). An increase to 4.25 at 21 PV following the addition of lactate was observed. It should be noted at this time that the addition of lactate to the *influent* AMD resulted in a pH increase of 1.2 to 1.3 standard units. Thus much of the increase in *effluent* pH following the addition of lactate should be interpreted with this fact in mind. The alkalinity level after 2 PV was 106 mg/l. After this point, the effluent became acidic and declined to 699 mg/l titratable acidity after 21 PV (Figure 2a). As was observed in Eko-Compost, an anomalously high titratable acidity value (1469 mg/l) was obtained during the second sampling round (7 PV, 77 days) with corresponding increases in Fe and Mn levels. However, a circumneutral pH value was observed (6.23), casting doubt on the validity of the acidity value. Effluent SO₄ and TDS levels were not notably different from influent levels. A maximum pre-lactate addition TOC concentration of 15 mg/l was observed after 2 PV and ranged between 4 and 7 mg/l through 16 PV. Nitrate N was below detection (0.05 mg/l) through 16 PV. Following the addition of lactate, TOC values increased to 1100 mg/l and TKN levels decreased from 6.1 mg/l at 17 PV to 1.0 mg/l following addition of lactate.

Effluent Al concentrations were below detection limit (<0.02 mg/l) through 9 PV, after which point they increased to 59.1 mg/l and 149 mg/l after 17 and 21 PV, respectively (Figure 2b). Total Fe levels increased steadily to a maximum concentration of 220 mg/l after 14 PV. A decrease to 97.4 mg/l was observed by 21 PV. With the exception of Fe concentrations of 115 mg/l and 97.4 mg after 19 and 21 PV (post-lactate addition), respectively, where all of the Fe was in the Fe²⁺ form, Fe concentrations in subsequent samples (14 through 17 PV) were comprised of 63% to 99% Fe³⁺. Effluent Mn concentrations ranged between 7.64 and 1.62 mg/l and exhibited a trend toward decreasing concentrations as influent exceeded 14 PV. Zinc concentrations were below detection in all effluents through 17 PV (Figure 2c).

4.1.3 Great Western Mushroom Compost

Effluent EC levels showed an extreme increase (8.91 to 15.49) over influent values (2.45) through the first 21 days (1 PV) of the study. After 4 PV the EC level decreased to 2.78 and remained below 3.39 until the addition of lactate. Effluent pH levels rose to an initial maximum of 7.45 at 1 PV and remained above 6.38 throughout the study (Figure 3a).

ACIDITY AND ALKALINITY

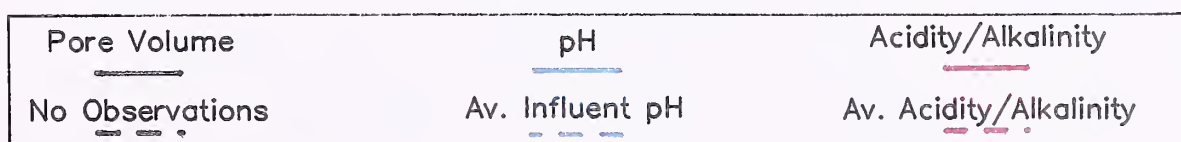
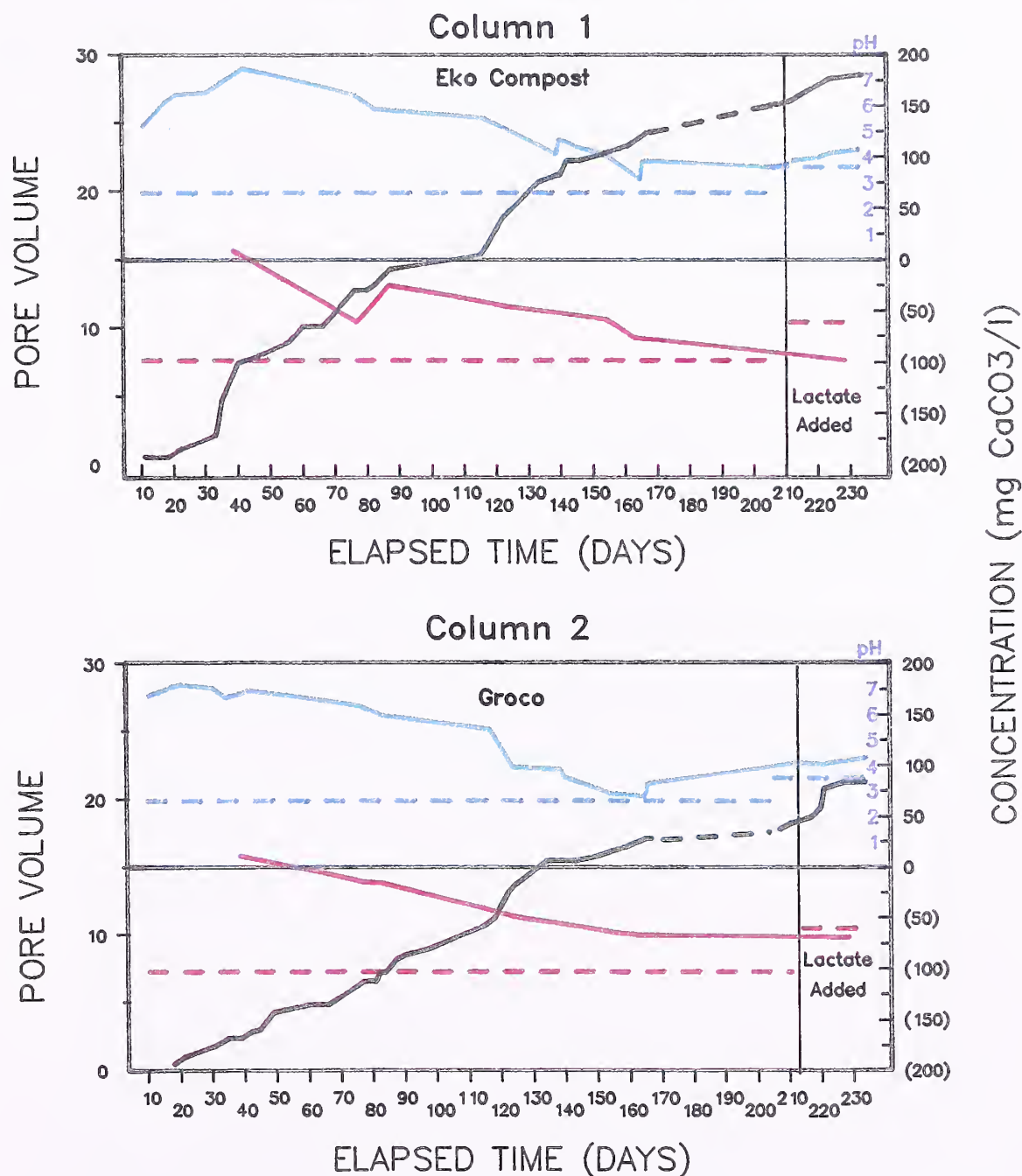


Figure 2a. Substrate mean influent and effluent pH and acidity/alkalinity concentrations.

ALUMINUM AND IRON

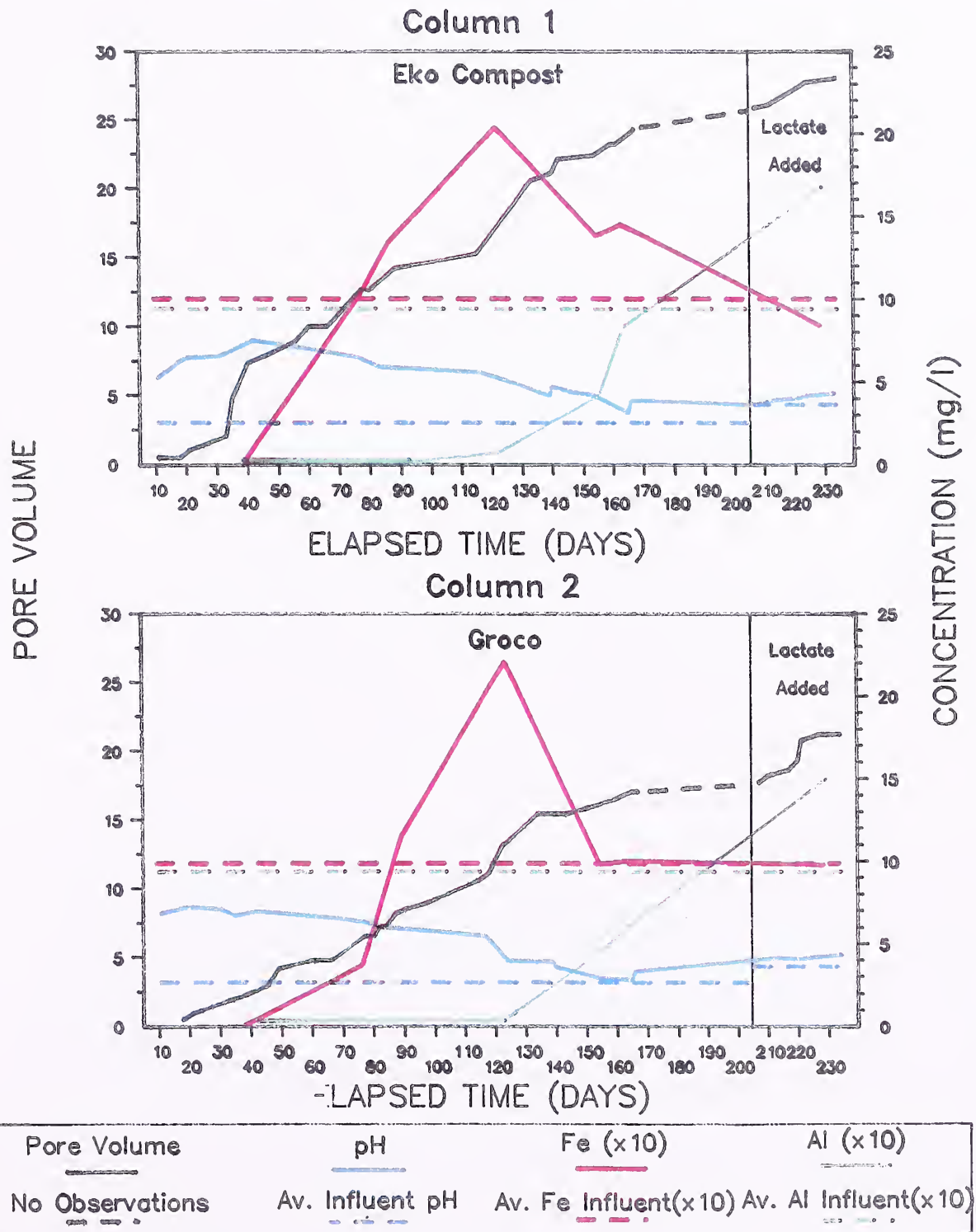


Figure 2b. Substrate mean influent and effluent pH, Al and Fe concentrations.

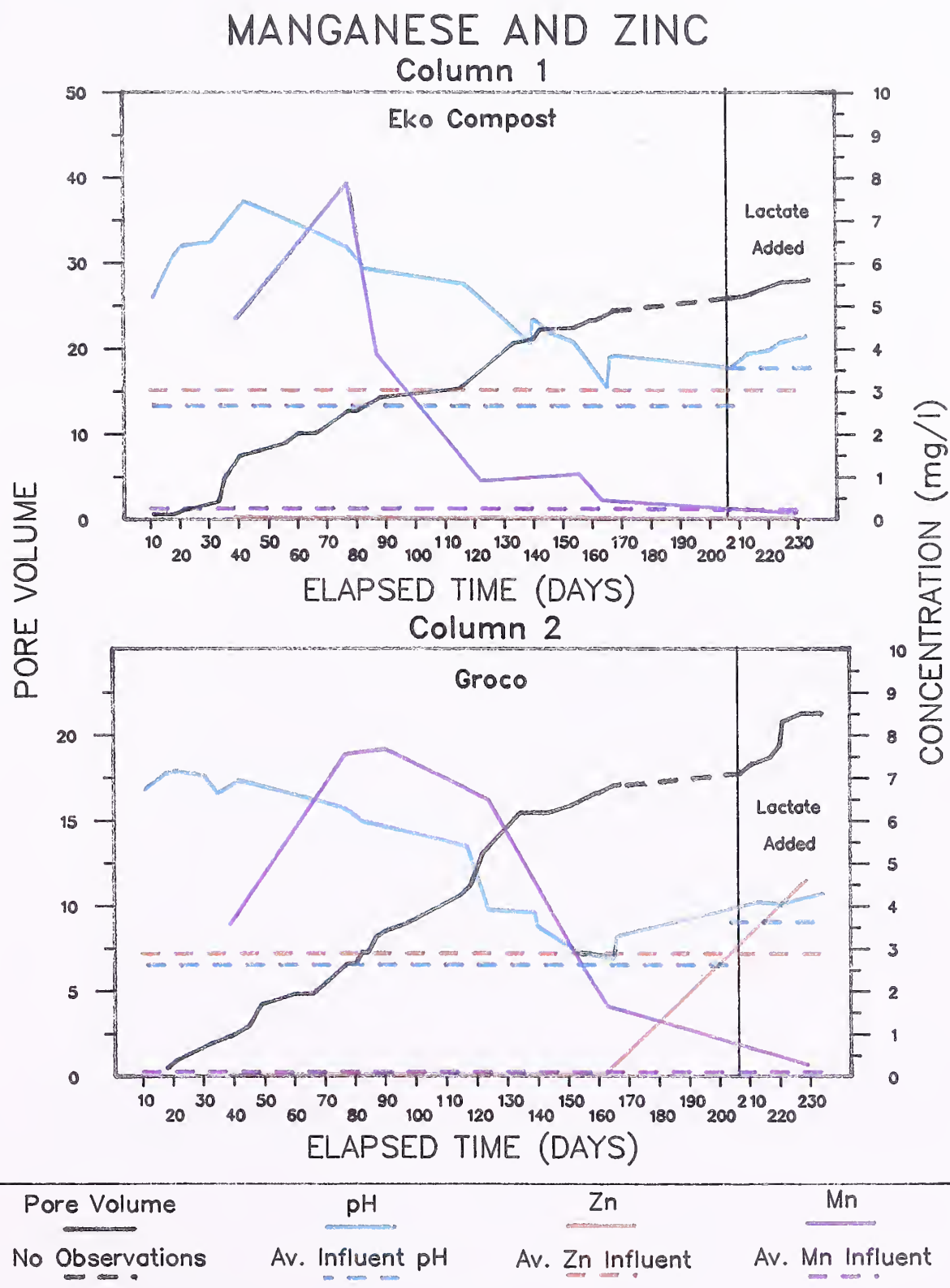


Figure 2c. Substrate mean influent and effluent pH, Mn and Zn concentrations.

Eh levels ranged between 95 mv and 260 mv through 19 PV. Net alkalinity was observed throughout the study and ranged from an initial maximum of 5170 mg/l to a minimum of 351 mg/l, showing an increase to 2480 mg/l after the addition of lactate (21 PV) (Figure 3a). Sulfate effluent values were initially greater than influent levels, probably due to the contribution of SO_4 from gypsum ($\text{CaSO}_4 \cdot 2\text{H}_2\text{O}$) in the substrate, used as a flocculent to promote decomposition of organic matter, but were very similar to influent levels after 4 PV. Initial (4 PV) TOC (1870 mg/l) and nitrate N (0.90 mg/l) levels were elevated, especially TOC, compared with values observed during the remainder of the study, which ranged between 13 mg/l and 22 mg/l and < 0.05 mg/l, respectively. The addition of lactate increased TOC levels to 654 mg/l from 22 mg/l and TKN from 3.5 mg/l at 18 PV to 4.7 mg/l.

Effluent Al concentrations were < 0.2 mg/l throughout the study. Total Fe levels were < 0.1 mg/l for the duration of the study (Figure 3b). Concentrations of Mn ranged between 0.53 and 1.47 mg/l and appeared to stabilize near the latter value after 14 PV. Zinc levels ranged between .01 and 0.15 mg/l (Figure 3c).

4.1.4 United Foods Mushroom Compost

Effluent EC levels were extremely high (> 20 mmhos/cm, off meter scale) through the first 35 days (3 PV) of the study. After 42 days (3 PV) they had declined to 3.04 and ranged between 2.58 and 5.05 mmhos/cm through 20 PV. Effluent pH values varied between 5.85 and 7.20 throughout the study (Figure 3a). Eh levels ranged between an initial (1 PV) minimum of 93 mv to 493 mv. All effluent samples had net alkalinity, ranging between 167 mg/l and a maximum of 1740 mg/l after 8 PV. Alkalinity dropped from 1250 mg/l at 10 PV to between 167 and 237 mg/l through 20 PV (Figure 3a). With the addition of lactate alkalinity increased significantly to 2700 mg/l at 24 PV. Sulfate effluent levels were similar to influent levels but increased by greater than 1000 mg/l over influent levels with the addition of lactate. This level corresponded with maximum alkalinity values. Concentrations of TOC ranged between 16 and 19 mg/l between 14 and 19 PV following values of 570 and 70 mg/l after 3 and 10 PV, respectively. A maximum initial nitrate N concentration was observed after 3 PV, after which point N concentrations remained < 0.05 mg/l. With the addition of lactate, TKN levels decreased to 4.3 mg/l from 4.7 mg/l at 20 PV and TOC increased to 1270 mg/l.

Effluent Al concentrations were < 0.4 mg/l throughout the study. Total Fe levels ranged from an initial (3 PV) maximum of 4.1 mg/l to < 0.1 mg/l (Figure 3b). Manganese concentrations ranged between 0.47 and 2.8 mg/l. Zinc effluent concentrations were < 0.03 mg/l after an initial maximum of 0.21 mg/l (Figure 3c).

4.1.5 Peaco Peat

Effluent EC levels ranged between 1.42 and 2.86 mmhos/cm, increasing slightly to 3.30 mmhos/cm following the addition of lactate. Effluent pH was 6.19 after 1 PV and increased to 7.92 after 2 PV. A slow, steady decline to 4.87 was observed after 15 PV.

ACIDITY AND ALKALINITY

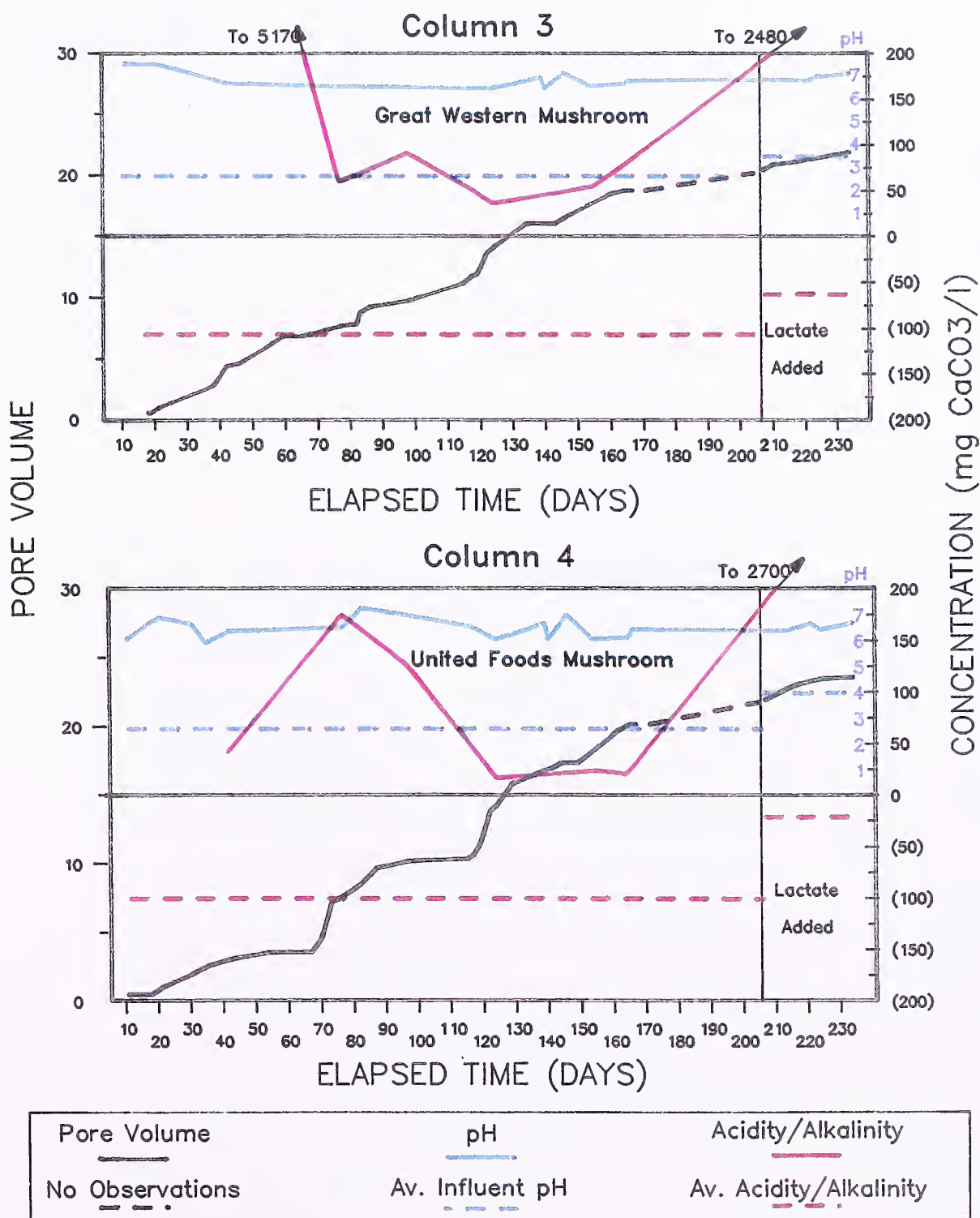
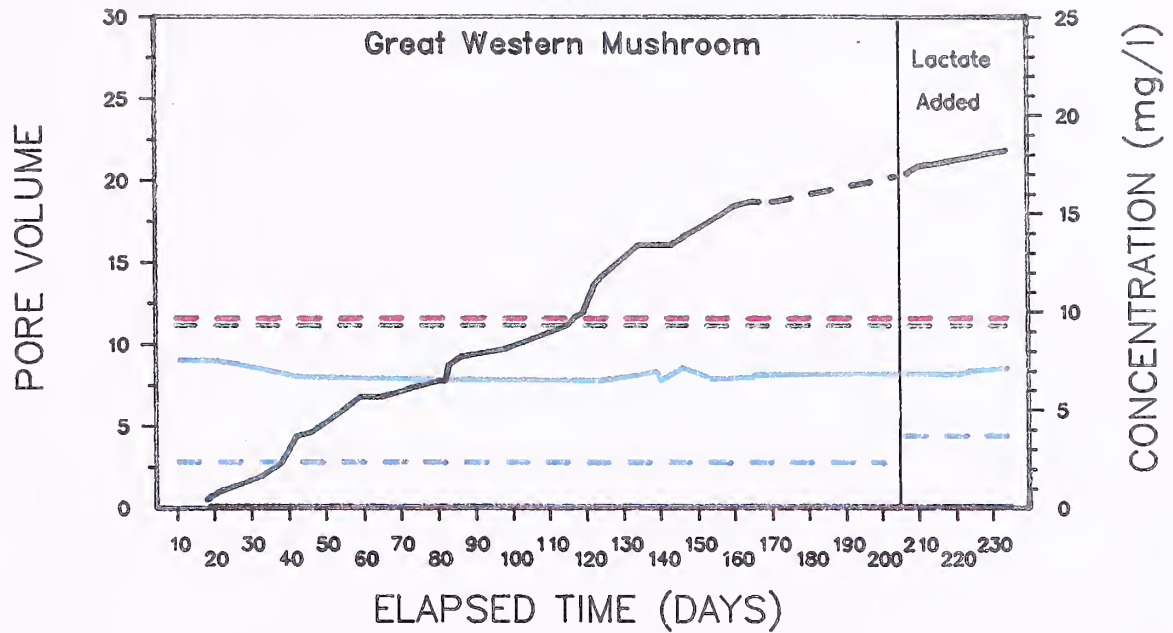


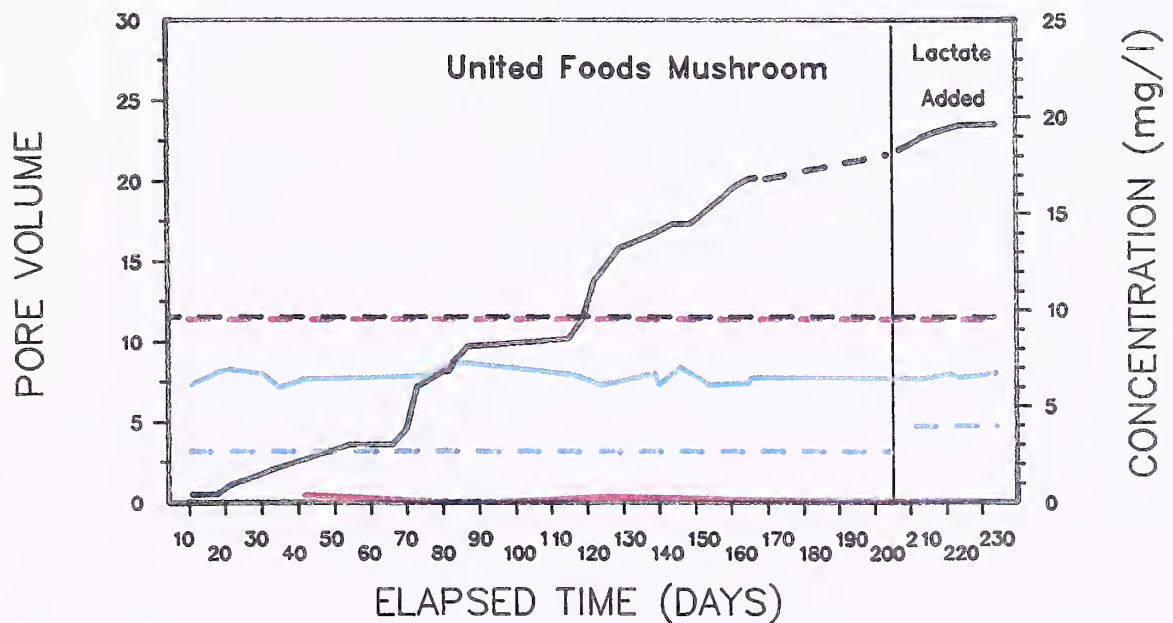
Figure 3a. Substrate mean influent and effluent pH and acidity/alkalinity concentrations.

ALUMINUM AND IRON

Column 3



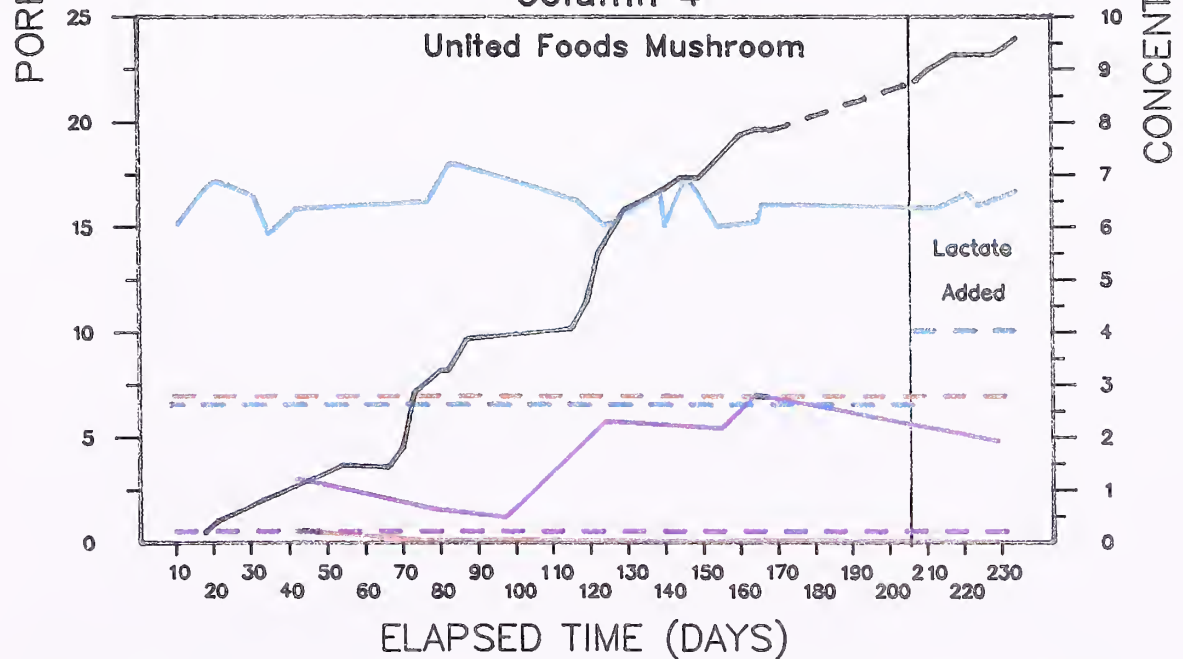
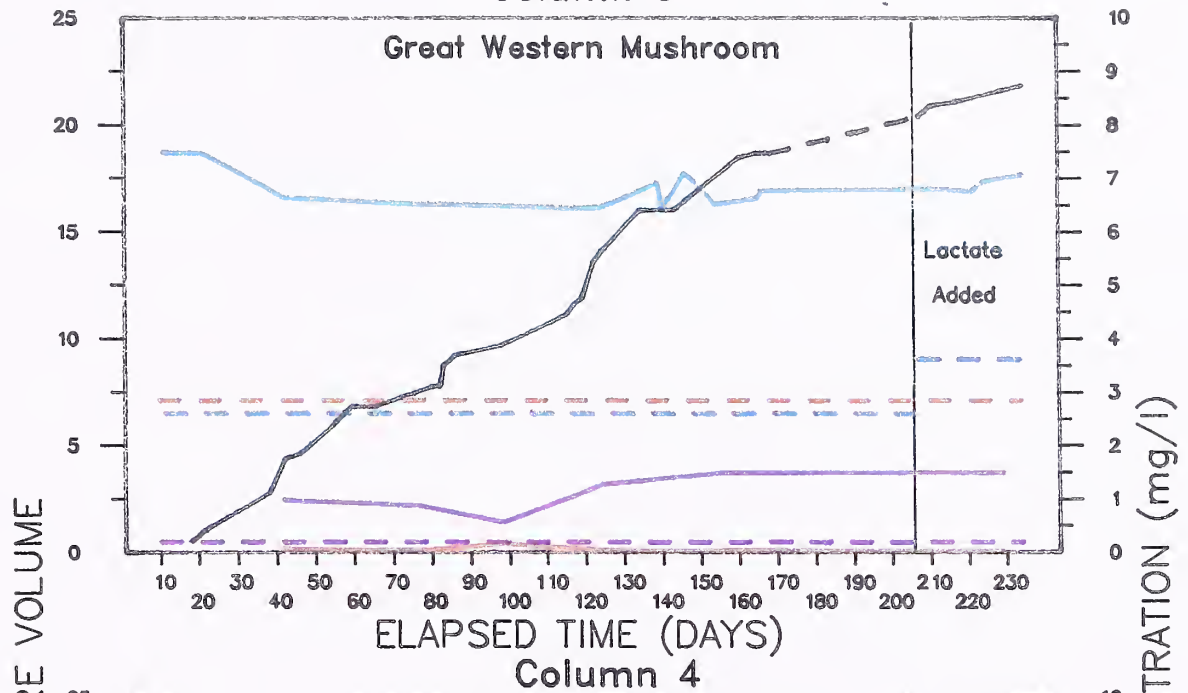
Column 4



Pore Volume	pH	Fe (x10)	Al (x10)
No Observations	Av. Influent pH	Av. Fe Influent(x10)	Av. Al Influent(x10)

Figure 3b. Substrate mean influent and effluent pH, Al and Fe concentrations.

MANGANESE AND ZINC Column 3



Pore Volume	pH	Zn	Mn
—	—	—	—
No Observations	Av. Influent pH	Av. Zn Influent	Av. Mn Influent
—	—	—	—

Figure 3c. Substrate mean influent and effluent pH, Mn and Zn concentrations.

Between 16 and 19 PV, pH ranged between 2.80 and 3.48 (Figure 4a). Eh varied between 287 and 877 mv through 19 PV and between 692 and 879 mv after the addition of lactate. A maximum alkalinity value of 108 was obtained after 5 PV, declining to 53 mg/l after 7 PV and becoming acidic (296 mg/l) after 11 PV. Acidity increased to 850 mg/l by 18 PV and reached a maximum of 1350 mg/l after 20 PV, following the addition of lactate (Figure 4a). Sulfate levels ranged between 1500 and 1870 mg/l and showed no significant change from influent levels. Levels of TOC ranged between 2 and 12 mg/l through 18 PV, increasing to 900 mg/l after the addition of lactate. Concentrations of nitrate N decreased from an initial value of 0.43 mg/l to < 0.05 mg/l through 18 PV and TKN increased to 2.4 mg/l from 1.5 mg/l at 18 PV after lactate was added.

Effluent Al concentrations were < 0.1 mg/l through 11 PV but increased to 87 and 121 mg/l after 17 and 18 PV, respectively. An Al concentration of 185 mg/l at 20 PV was obtained following the addition of lactate. Total Fe remained < 0.4 mg/l until 11 PV. After 17 and 18 PV, Fe concentrations dropped to 37.2 and 44.2 mg/l, respectively (Figure 4b), with greater than 97% in the Fe^{3+} form. A maximum Fe concentration of 97.4 mg/l, 46% of which was in the Fe^{3+} form, was obtained after the addition of lactate. Concentrations of Mn ranged between 0.28 and 0.57 mg/l through 18 PV and dropped to < 0.02 mg/l after the addition of lactate. An anomalously high value of 2.97 mg/l was observed after 11 PV and corresponded to the initial breakthrough in Fe (100 mg/l). The concentration of Zn was < 0.03 mg/l through 11 PV and increased to 0.93 mg/l after 18 PV (Figure 4c), corresponding to an observed increase in Al concentrations. After the addition of lactate, Zn decreased to 0.18 mg/l.

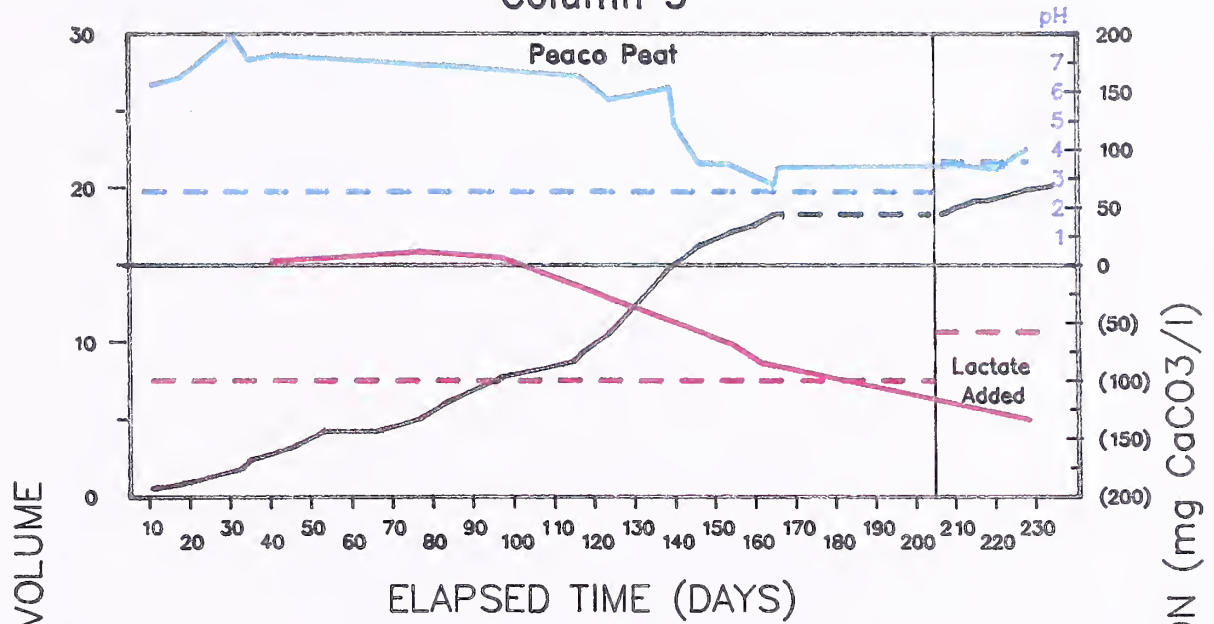
4.1.6 Farmers Peat

Effluent EC values ranged between 1.49 and 3.55 mmhos/cm throughout the study. Effluent pH increased from an initial (1 PV) value of 3.72 to 5.70 after 3 PV and then decreased to between 2.76 and 3.16 through 18 PV, after which point a slight increase to 3.89 was noted following the addition of lactate (Figure 4a). Eh values were between 493 and 999 mv, with the higher values generally occurring after 16 PV. Acidity levels exhibited an increasing trend from 158 mg/l after 3 PV to 972 mg/l after 20 PV and the addition of lactate (Figure 4a). An anomalously high value of 8560 mg/l was obtained after 7 PV and corresponded to increased Fe and Mn levels but is suspect because of a 4.47 pH value as compared to an acidity value of 669 at pH 2.78 at 12 PV. Concentrations of SO_4 in effluent showed no notable changes from influent concentrations throughout the study. A decrease in TOC from an initial value of 34 mg/l to 9 mg/l occurred after 18 PV, but increased to 1000 mg/l after the addition of lactate. Nitrate N decreased from 1.38 mg/l initially to < 0.05 mg/l through 18 PV. TKN decreased from 2.7 mg/l at 18 PV to 2.2 mg/l after lactate was added.

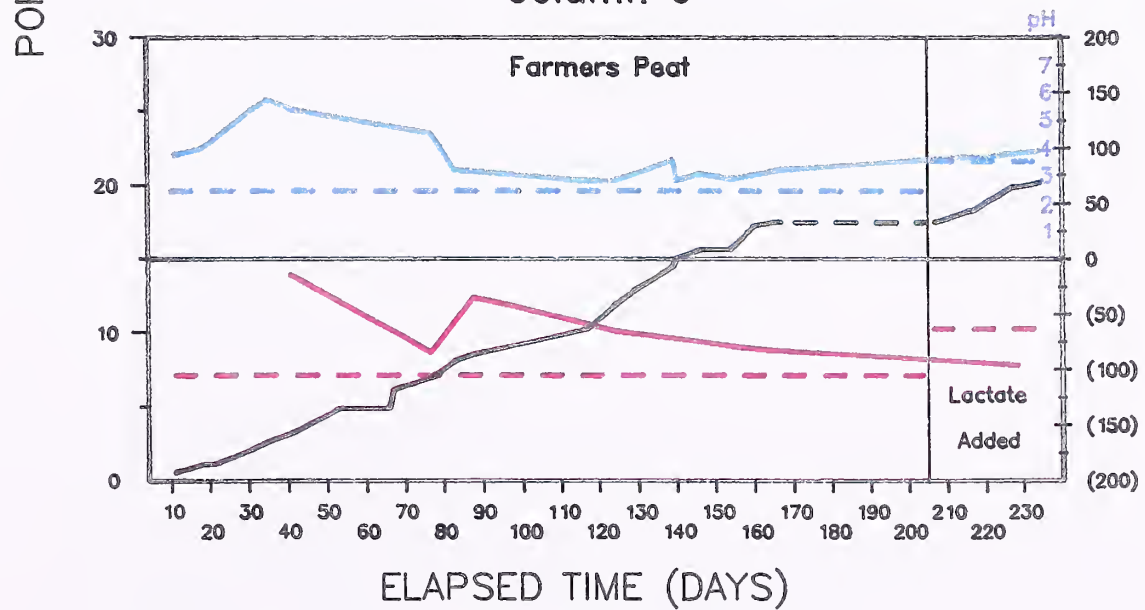
Effluent Al concentrations ranged between 2.0 and 6.4 between 3 and 9 PV but increased notably to 62.3 mg/l after 12 PV, continuing to a maximum concentration of 149 mg/l at 20 PV following lactate addition. Total Fe increased from an initial (5 PV) minimum of 9.0 mg/l to 55 mg/l after 12 PV (Figure 4b). A drop to 23.9 mg/l was observed after 17

ACIDITY AND ALKALINITY

Column 5



Column 6



Pore Volume	pH	Acidity/Alkalinity
No Observations	Av. Influent pH	Av. Acidity/Alkalinity

Figure 4a. Substrate mean influent and effluent pH and acidity/alkalinity concentrations.

ALUMINUM AND IRON Column 5

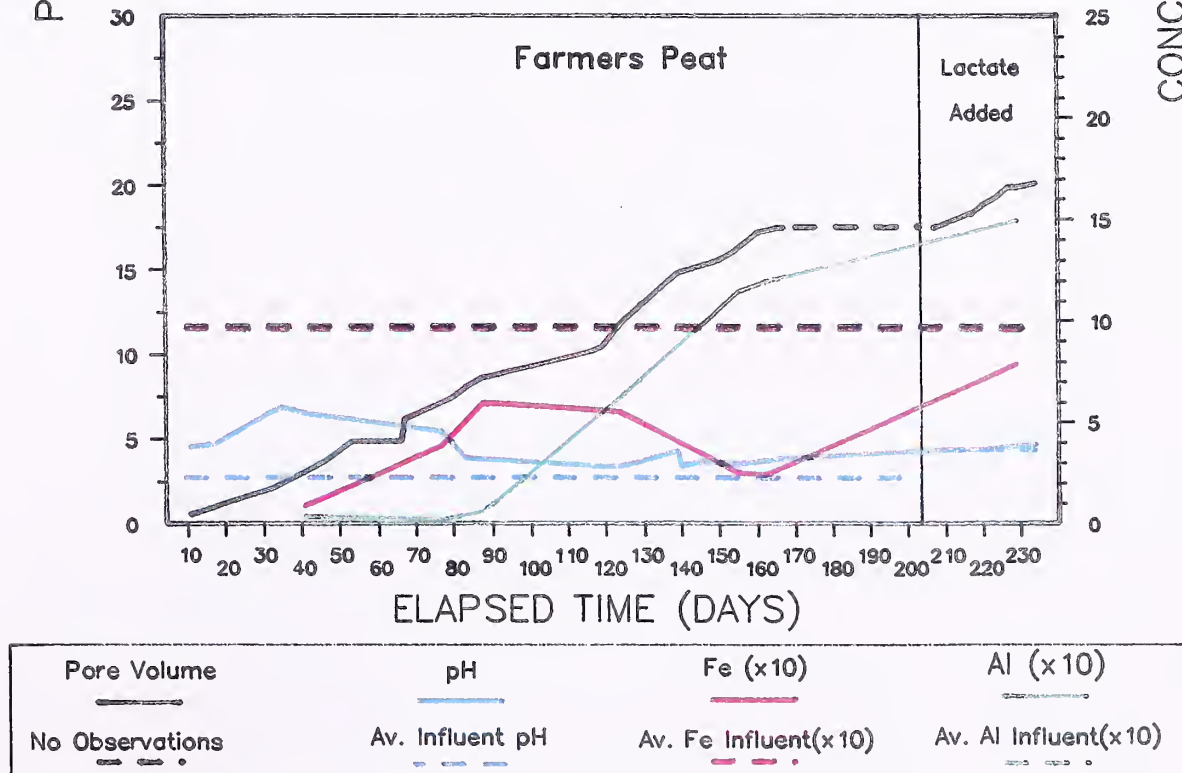
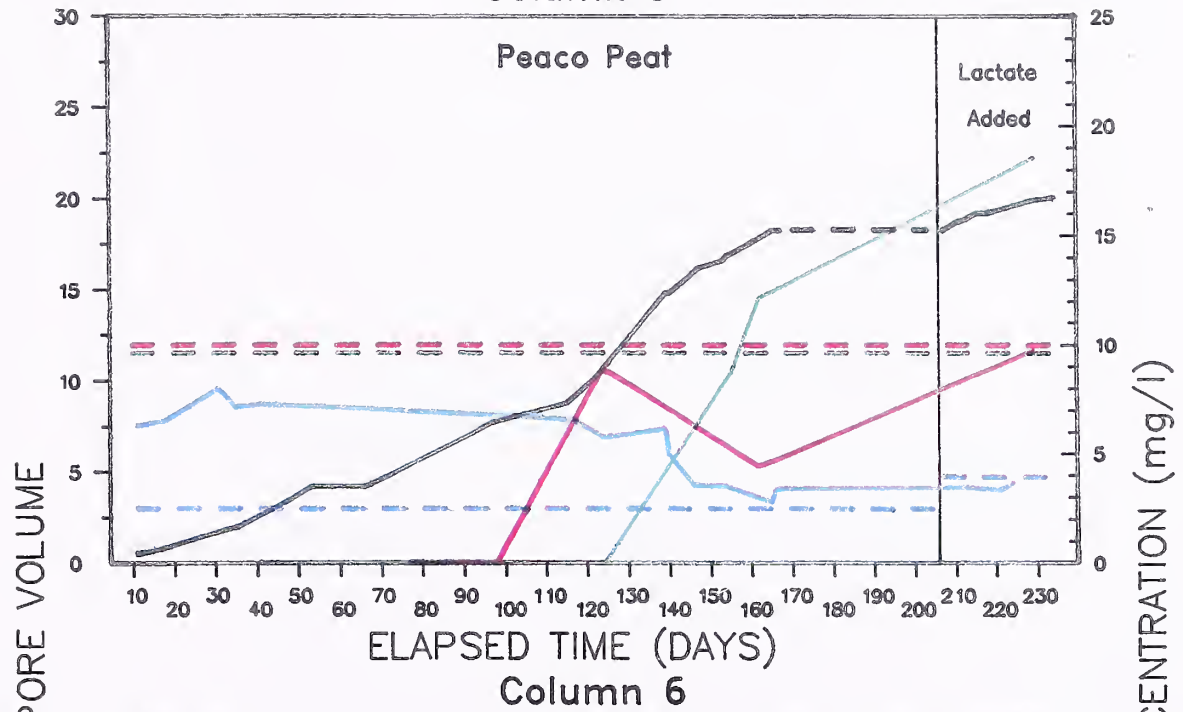


Figure 4b. Substrate mean influent and effluent pH, Al and Fe concentrations.

MANGANESE AND ZINC Column 5

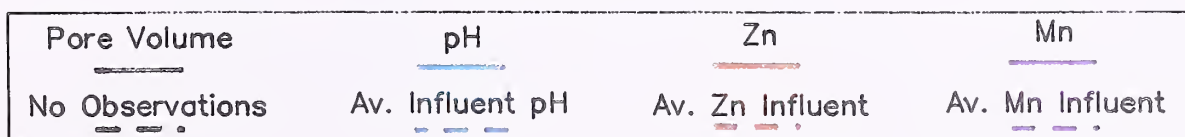
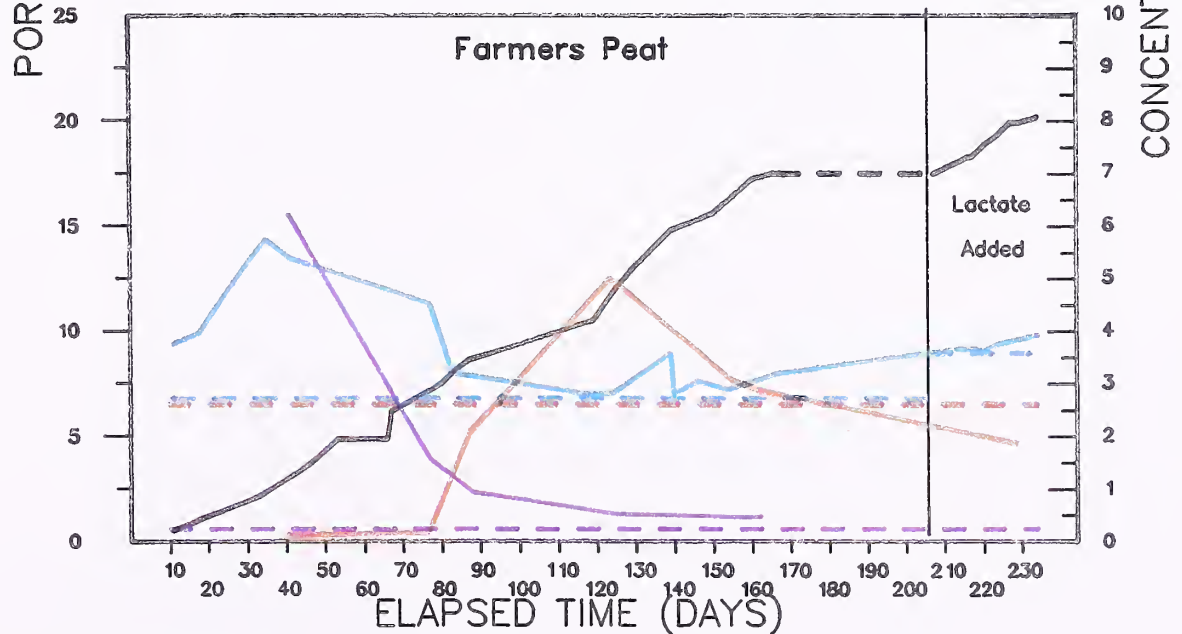
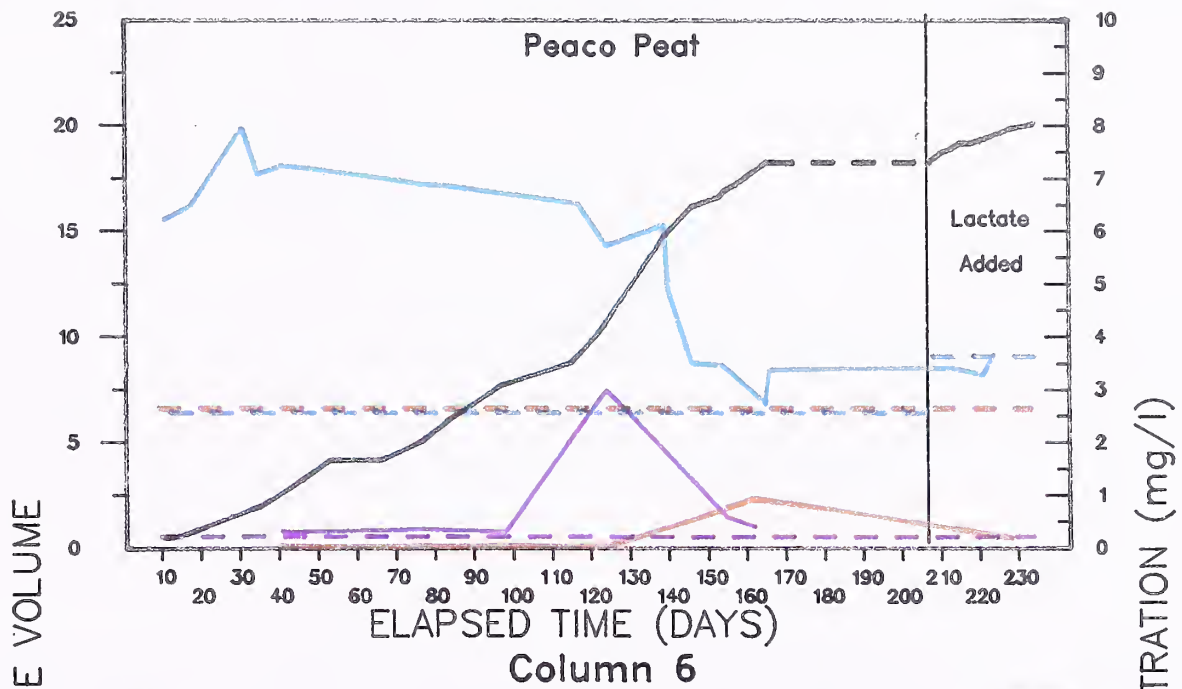


Figure 4c. Substrate mean influent and effluent pH, Mn and Zn concentrations.

PV. Greater than 96% of total Fe after 9 PV was in the Fe^{3+} form. The Mn concentration was a maximum of 6.19 after 3 PV and declined rapidly to 1.55 mg/l after 7 PV, afterwards exhibiting a slow temporal decrease to 0.45 mg/l after 17 PV and below detection (.02 mg/l) by the end of the study (21 PV). No Mn was detected by the end of the study (21 PV). Zinc concentrations increased from 0.09 mg/l at 3 PV to 4.98 mg/l after 12 PV, decreasing to 3.06 mg/l after 17 PV and to 1.84 mg/l after 20 PV and the addition of lactate (Figure 4c).

4.1.7 General Trends in Effluent

a. Acidity-Alkalinity/pH

All substrates initially decreased acidity levels in the AMD, most likely due to inherent neutralization capacity (Figure 14, forthcoming subsection). Effluent data indicate that for both composted wood waste/sewage sludges and both peats, pH and alkalinity declined (acidity increased) in proportion to the number of PV passing through the columns. Acidity increased steadily from slightly acidic or slightly basic to acid by completion of the study. As is evident in Figure 4a, both peats were slightly less effective at neutralizing acidity than the composted wood wastes/sewage sludges. Values for pH declined from early maximum values between 6 and 8 to between 3.0 and 4.5.

Conversely, both mushroom composts exhibited a relatively uniform range of pH (6 to 7.8) throughout the study. Elevated alkalinity values (especially in Great Western) occurred in the early stages of the study and eventually declined to between 200 and 750 mg/l. A significant increase in alkalinity is apparent in both mushroom composts following lactate addition, indicating that in the latter stages of the study, alkalinity was likely derived in part from microbial activity.

b. Iron

All substrates removed > 99% of Fe initially, with the exception of Farmers peat (92 %). This was probably due to the electrostatic and specific sorption by organics. Effluent Fe concentrations for both of the composted wood waste/sewage sludges and both peats showed temporal variations with maximum concentrations occurring between approximately 8 and 11 PV. Variation was not as great in the peats. "Breakthrough" of Fe in both composted wood wastes/sewage sludges and both peats is evident in Figures 2b and 4b, respectively, most likely following the exhaustion of the cation exchange capacity. Following breakthrough, Fe increased in proportion to AMD flow for both composted wood waste/sewage sludges and both peats between 8 and 16 PV. In the case of both wood waste/sewage sludges, extremely large increases were observed at 14 (Groco) and 17 PV (Eko-Compost), to the point where effluent Fe was notably greater than influent concentrations. Effluent Fe concentrations decreased following these peaks, but remained near or above influent values until the end of the study. There was no apparent consistent affect of pH on Fe concentrations after "breakthrough" had occurred. The fact that Fe concentrations remained elevated in some substrate effluents even at pH values greater than those required to precipitate $\text{Fe}(\text{OH})_3$ indicate that the microbial oxidation of Fe^{2+} to Fe^{3+}

and/or the precipitation of $\text{Fe}(\text{OH})_3$ were kinetically limited, possibly by inadequate residence time. It may also be possible that organically bound Fe complexes (chelates) in solution contributed to this effect.

Effluent Fe concentrations in both mushroom composts showed no significant temporal increase with increasing AMD flow and did not appear to be affected by slight temporal flow variations. Removal was greater than 99 % throughout the study.

c. Aluminum

Aluminum removal was greater than 95 % in all substrates during the first 90 days of the study (Figures 2b through 4b), probably due to the sorptive mechanisms responsible for initial Fe removal. Effluent Al concentrations increased in direct proportion to the amount of AMD passing through the columns in both wood waste/sewage sludges and both peats, following an Al "breakthrough", which occurred at a later point in time (greater PV) than did the first significant increases in Fe concentrations. In general, Al concentrations were inversely proportional to pH, showing a marked increase (breakthrough) when pH dropped below approximately 4.0. Slight variations in pH below this value did not appear to significantly affect Al concentrations. Concentrations in both mushroom composts showed no significant increase with increased AMD volume as removal was > 99 % throughout the study.

d. Manganese and Zinc

Manganese concentrations were, in general, greater than influent values for all substrates (Figures 2c through 4c), with both wood waste/sewage sludges exhibiting the greatest concentrations of Mn, although Mn did decrease with time. Both peats had Mn concentrations near or slightly greater than influent concentrations, with Farmers peat exhibiting significantly higher initial Mn values. Final Mn concentrations were greatest in the mushroom composts. It should be noted that Mn concentrations in the AMD *influent* were below detection (< 0.02 mg/l) for the second half of the study (after approximately 120 days). Unlike Fe and Al, there was no initial decrease of Mn associated with exchange/sorption capacity, suggesting a preference for Fe and Al over Mn in exchange reactions.

Concentrations of Zn in effluent were much lower than influent concentrations (removal > 99%) for all substrates throughout the study with the exception of the peats and a single elevated value after the addition of lactate to Groco. Zinc removal ranged between 99 % through 12 PV to 66 % for Peaco peat and from 97 % initially to a minimum of 82 % for Farmers peat. It is probable that exchange/sorption mechanisms played a significant role in the removal of Zn. This hypothesis is corroborated by the substrate metal fractionation results presented in Section 4.4.4.

4.2 DEPTH SAMPLING CHEMISTRY

Two separate sampling rounds were performed on the ceramic cup sampling ports. In general, the results for both rounds were very similar with respect to differences between substrates. Results from the second sampling round are presented in Figures 5a through 7b. Raw data from both sampling rounds is presented in Appendix C. The following results will be discussed in terms of distance from the *bottom* of the substrate in the column. It should be noted that the results presented here represent the substrate chemistry at a single point in time and that analyte concentrations and chemical processes most likely were different for a given depth earlier in the study and after sampling.

4.2.1 Oxidation/Reduction Potential (Eh)

All columns showed a decrease in Eh values with increasing distance from the influent port (bottom of column). This is most likely a result of decreased O₂ values in response to increased microbial activity from the influent port. The most significant decreases were observed in both of the mushroom composts (Figure 6a), where reducing conditions (negative Eh values) were reached in the upper 33 cm. Eh levels were generally slightly lower overall in the wood waste/sewage sludges than in the peats. It is worth noting that SO₄ reduction was observed to be occurring in areas where port sampling yielded solution Eh values greater than - 100 mv, the theoretical maximum value above which microbial SO₄ reduction by *Desulfovibrio spp.* cannot take place. It is possible that SO₄ reduction was occurring in areas where flow and O₂ was very limited (dead spots) or it may be that O₂ was preferentially uptaken during vacuum sampling of the ceramic cups, yielding artificially high O₂ and thus Eh values.

4.2.2 pH

In general, pH values increased with depth from the bottom of the substrate. Anomalous high values observed at some depth increments in a given column may be due in part to the proximity of the ceramic sampling cup or to a discrete zone of increased microbial activity. Values for pH were in general an order of magnitude lower in the bottom 8 to 16 cm than in the overlying substrate, with the exception of Farmers peat, which showed a relatively uniform pH distribution with depth. Maximum circumneutral pH values were observed in the upper 50 cm of Great Western Mushroom compost (Figure 6a), coinciding with zones of observed SO₄ reduction (Section 4.7). Although the maximum pH for the United Foods mushroom compost (5.46) at the uppermost sampling interval (77 cm) was only slightly greater than that observed for Peaco and Farmers (Figure 7a) peat (5.09 and 5.29, respectively), the effluent pH (6.09) was much greater than that of either peat (2.71 and 3.16, respectively). This probably explains the better overall performance of the mushroom compost relative to the two peats.

CONCENTRATION VS. DEPTH

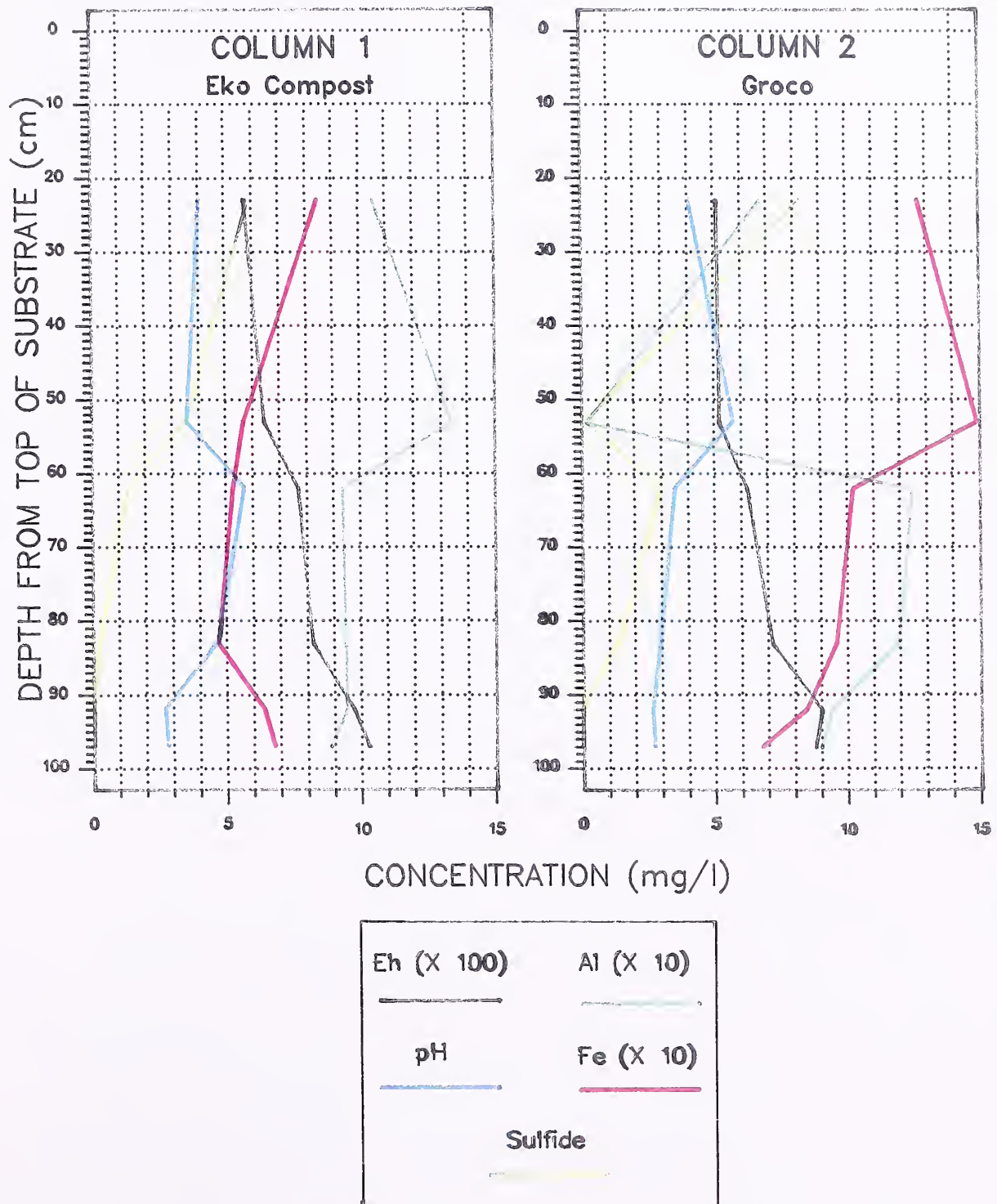


Figure 5a. Substrate pore water Eh, pH, S²⁻, Al and Fe concentrations by depth.

CONCENTRATION VS. DEPTH

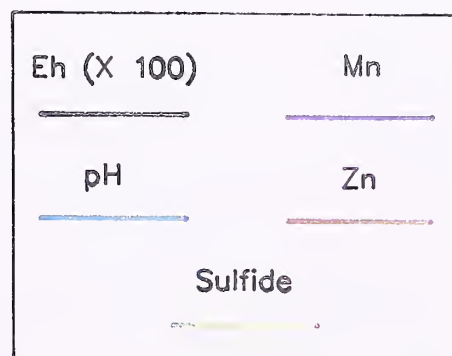
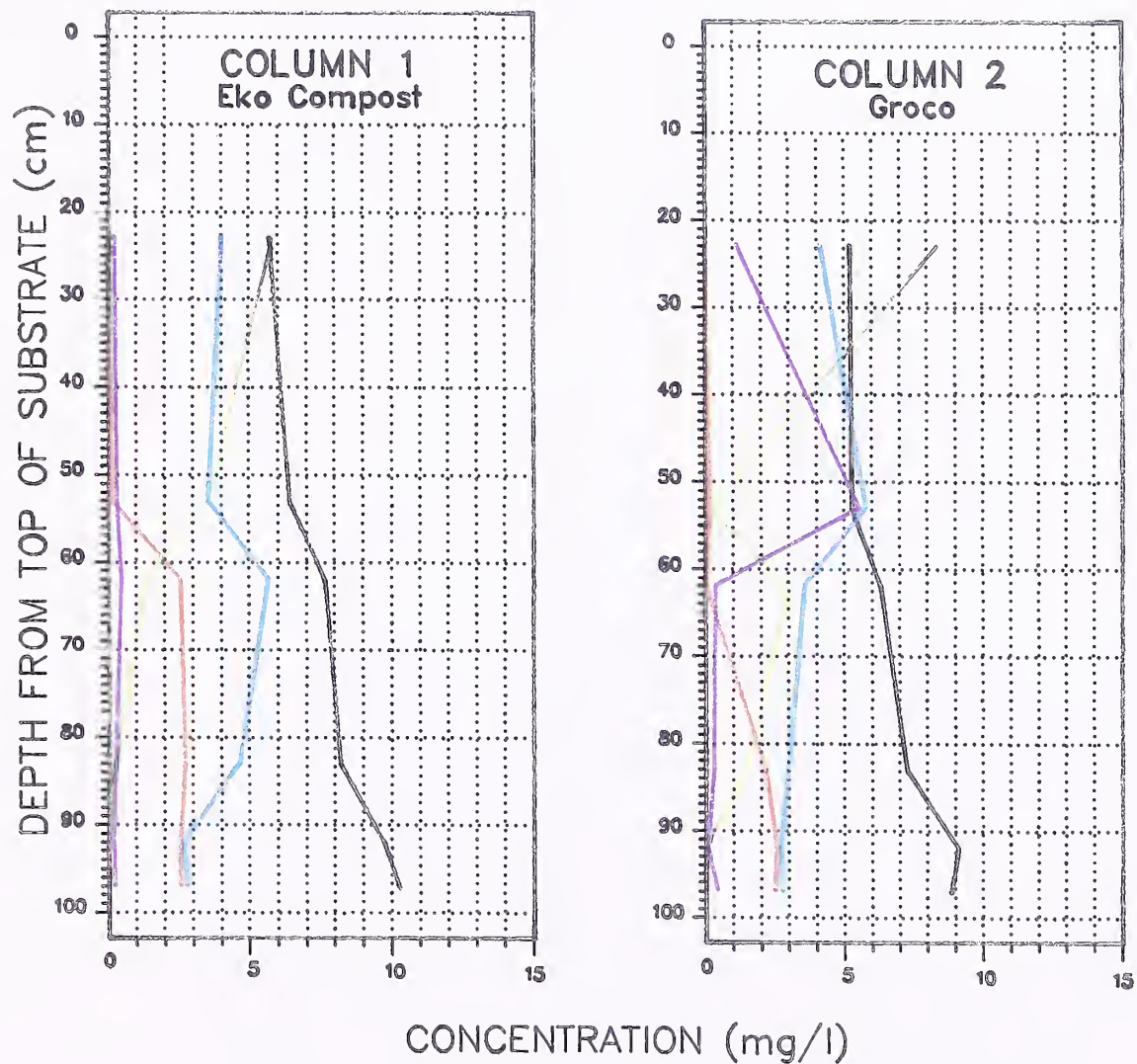


Figure 5b. Substrate pore water Eh, pH, S^{2-} , Mn and Zn concentrations by depth.

CONCENTRATION VS. DEPTH

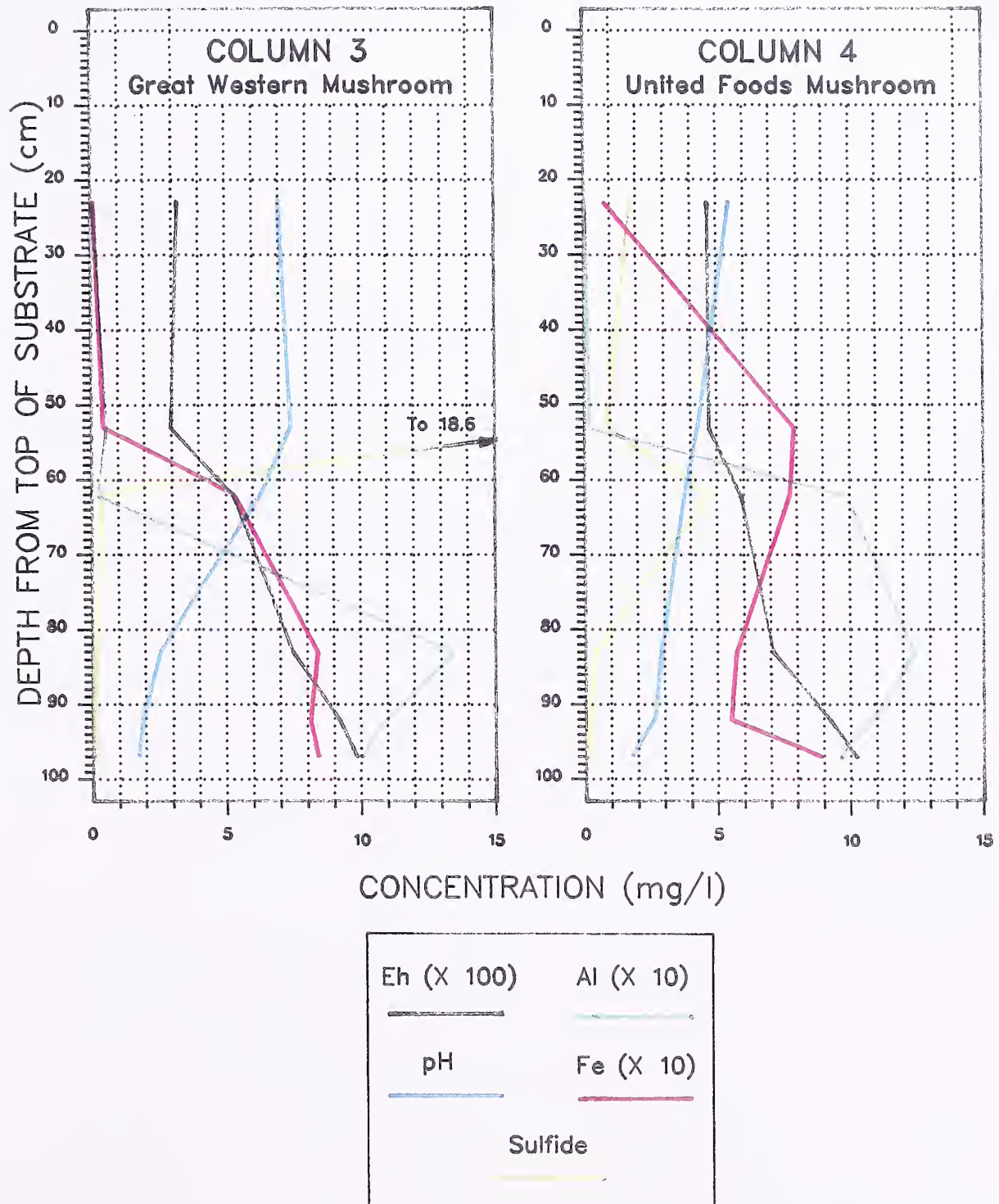


Figure 6a. Substrate pore water Eh, pH, S²⁻, Al and Fe concentrations by depth.

CONCENTRATION VS. DEPTH

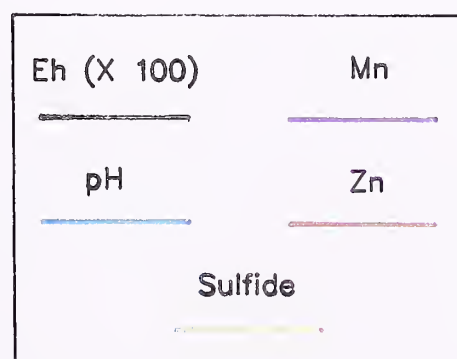
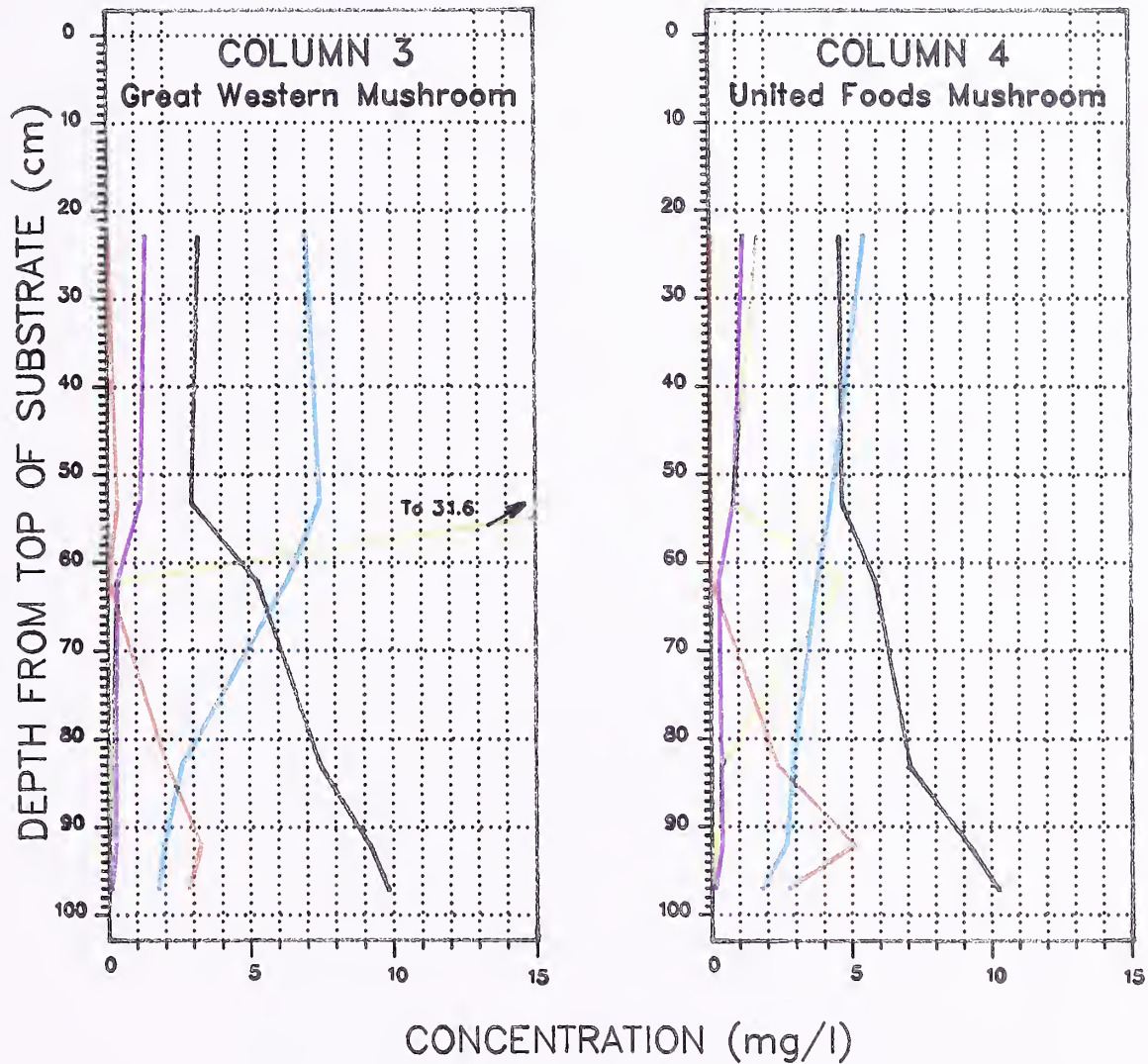


Figure 6b. Substrate pore water Eh, pH, S^{2-} , Mn and Zn concentrations by depth.

CONCENTRATION VS. DEPTH

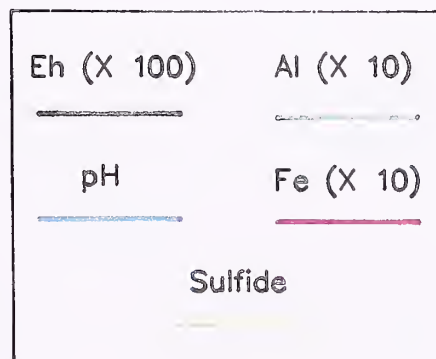
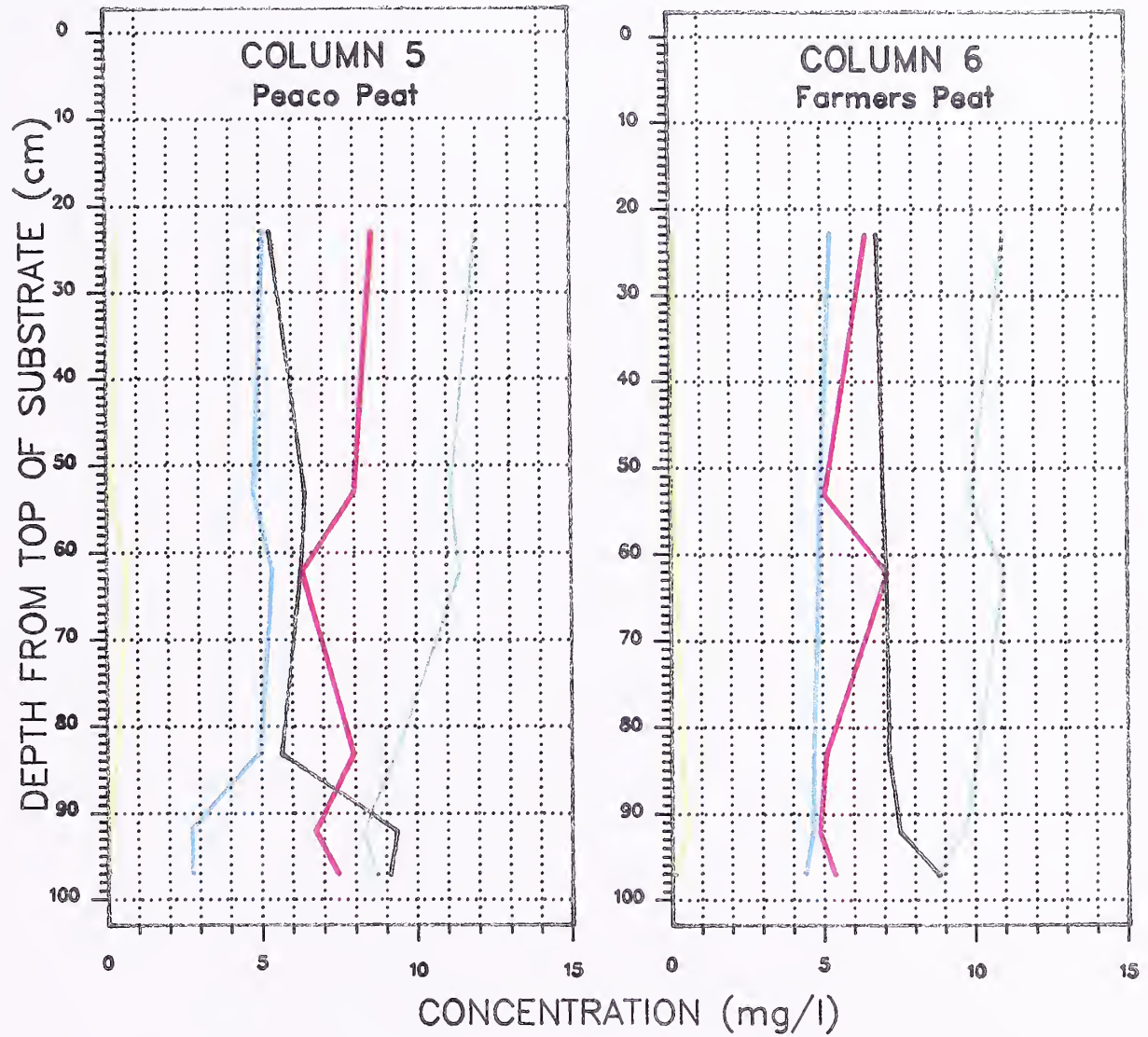


Figure 7a. Substrate pore water Eh, pH, S^{2-} , Al and Fe concentrations by depth.

CONCENTRATION VS. DEPTH

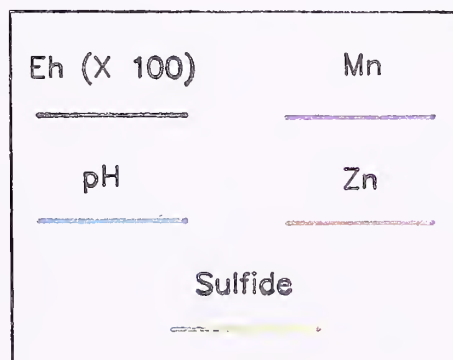
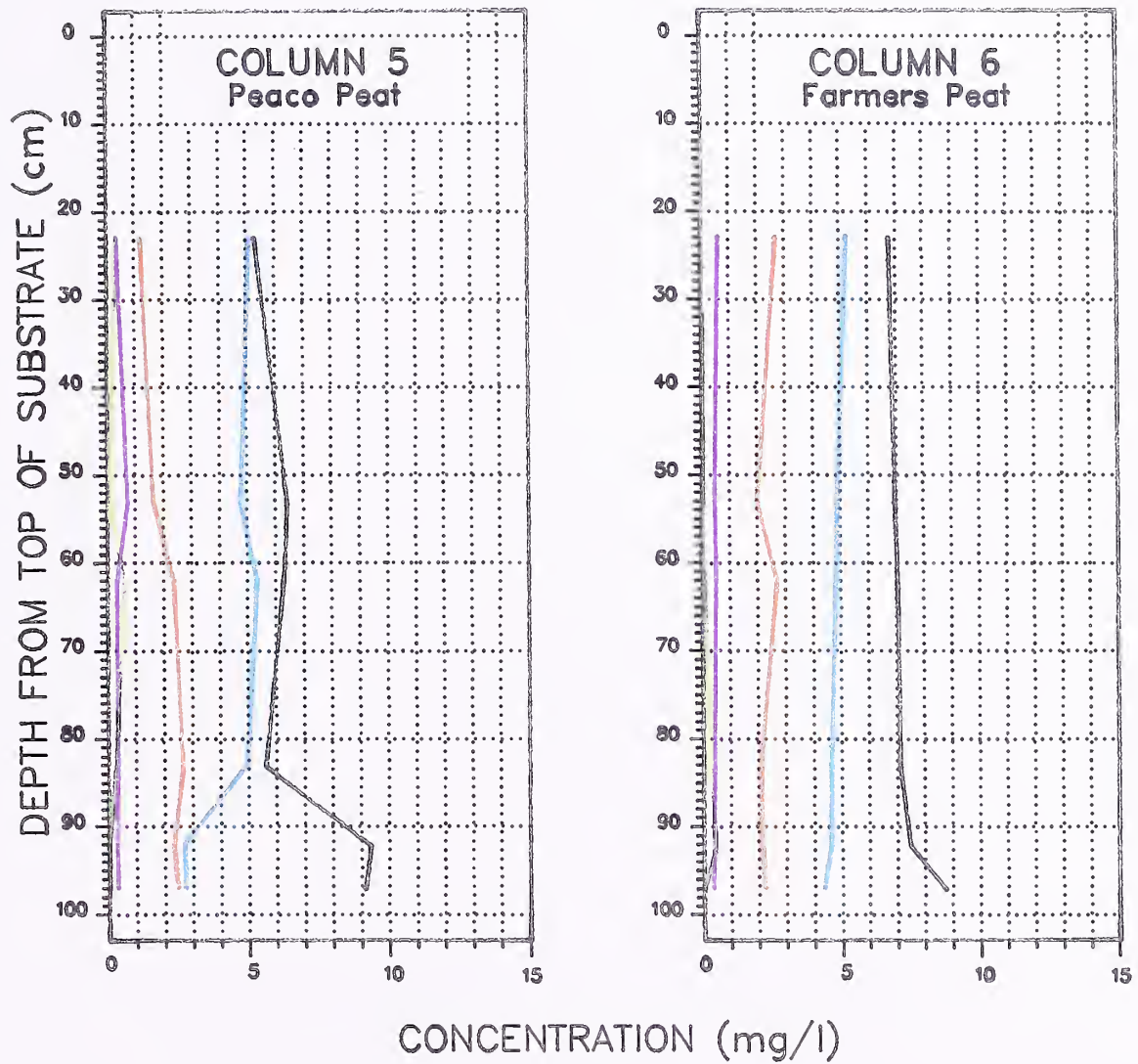


Figure 7b. Substrate pore water Eh, pH, S^{2-} , Mn and Zn concentrations by depth.

4.2.3 Sulfide

Dissolved sulfide (S^{2-}) levels are generally greater at higher pH values (Figures 5a through 7b). This agrees with thermodynamic data. Also, S^{2-} concentrations are in general greatest in the upper part of the columns. It is not clear if greater S^{2-} concentrations are responsible for lower metal concentrations or if the elevated S^{2-} values simply represent copious amounts of S^{2-} in excess of those levels necessary for the precipitation of the various metals. In either case, within a given substrate, metal levels appear to correlate more closely to pH than to S^{2-} levels. It may be possible that the use of a suction syringe to obtain port samples resulted in the preferential removal of some H_2S gas from solution, thereby complicating the results. Dissolved S^{2-} levels do not correlate well with the residual metal fraction (Section 4.4) for a given depth within a column for any metal. These factors indicate heterogeneity of geochemical conditions within the columns

4.2.4 Aluminum

Overall, Al concentrations showed a strong inverse relationship with pH at pH values less than approximately 4.5 to 5.0. This is likely due in part to the relative insolubility of Al hydroxyoxides and basic sulfates above these pH values. Pore water concentrations of Al were slightly lower in the bottom 8 cm in both peats and Eko-Compost (30 cm) and increased above this point. This trend was apparent in Groco, with the exception of lower Al concentrations at the 47 cm sampling interval associated with higher relative pH values. Conversely, Al levels showed a dramatic decrease in the upper 33 cm in both mushroom composts (Figure 6a) in association with an increase in pH.

4.2.5 Iron

Iron pore water concentrations were not strongly affected by depth of substrate for either of the wood waste/sewage sludges (Figure 5a) or peats (Figures 7a). In general, there were slight increases in Fe concentration with increasing distance from the column base for these substrates. Both mushroom composts had Fe levels similar to the other substrates in the lower 30 to 47 cm, but exhibited a significant decrease in the upper 50 cm (United Foods) and 33 cm (Great Western) as pH values increased.

4.2.6 Manganese

In general, there was not a great difference in Mn pore water concentrations with depth between substrates (Figures 5b through 7b). The exception is the elevated levels observed in the upper 33 cm of both mushroom composts and Groco, which correspond to the lowest observed Eh values. A slight overall increase with distance from substrate bottom is evident in the peats and Eko-Compost.

4.2.7 Zinc

Zinc pore water concentrations in the lower 16 cm of all substrates are similar to influent concentrations. The majority of Zn removal occurred in the upper 50 cm in both of the wood waste/sewage sludges and both mushroom composts (Figures 5b and 6b). The lowest concentrations in Peaco peat occurred primarily in the upper 33 cm and were only about 50 % less than influent concentrations compared to greater than 95 % for the wood waste/sewage sludges and mushroom composts. Farmers peat showed the least variations in concentration with depth, with essentially no decrease in Zn concentrations.

4.3 LACTATE ADDITION

Sodium lactate was added to the *influent* AMD of each column at day 209 of the study to determine the effect of an added carbon source on microbial activity. It was thought that aggressive composting of the composted wood waste/sewage sludges and peats by non sulfate reducing microbes or an inadequate supply of readily available C may have resulted in less-than-optimum microbial sulfate reduction. As is evident in Figures 2a through 4a, the addition of lactate had little affect on the acidity/alkalinity levels (and thus the activity of sulfate reducing bacteria (*Desulfovibrio spp.*), which produce alkalinity through metabolism [1]) of both wood waste/sewage sludges and peats. However, alkalinity levels increased substantially (3 to 13 fold) in both mushroom composts, indicating increased activity of *Desulfovibrio spp.* This suggests that N, or other nutrients, are not a limiting factor to sulfate reducing microbial activity in the mushroom composts but may be in the other substrates. As would be expected, TOC levels increased in all substrate effluents (Appendix C). Concentrations of TKN decreased in both C, United Foods mushroom compost and Farmers peat and increased slightly in Great Western mushroom compost and Peaco peat. Eh levels dropped slightly in the peats and mushroom composts, most likely in response to increased microbial activity.

Metal levels in the sewage sludge/wood wastes and peats exhibit no apparent response to the addition of lactate. Where a slight increase or decrease in metals concentrations does appear, it is not possible to determine if the change is in response to added lactate or simply the continuation of a trend evident prior to lactate addition. In either case the results are not of sufficient magnitude to warrant further concern. Effluent Mn concentrations from the mushroom composts were not affected by lactate addition. Concentrations of Al, Fe and Zn remained low, suggesting that the mechanisms of removal for these metals was not affected by the addition of lactate. It should be noted again that the increase in pH observed in effluent following the addition of lactate is predominantly reflective of an increase of approximately 1.3 units in *influent* pH and a decrease of approximately 50 % in acidity. This may be due to the formation of lactic acid, which has a greater pK_a value than sulfuric acid.

4.4 SUBSTRATE METAL FRACTIONATION

Data from the analyses of the solid and sorbed fraction of metals in the substrates is presented below in Figures 8 through 10 and in Appendix D. An attempt to obtain a mass balance for each metal using dissolved influent and effluent concentrations (mg/l) and before and after treatment metal levels in substrate (mg/Kg) resulted in an excess and in some cases a deficiency for various metals and substrates. The total amount (mg) of a given constituent added to each column is given in Table E.3 in Appendix D. A likely explanation for a substrate removal value in excess of AMD input plus inherent substrate values for Fe is that filtering of influent water quality samples for dissolved metals (not all influent) led to a lower Fe analytical value than that which actually went into the column (total Fe). Excess Fe was in the colloidal form, most likely amorphous $\text{Fe}(\text{OH})_3$. Visual observations and formation of precipitates in influent lines corroborate this hypothesis. This may also be true for Al. In addition, substrate control (pre-AMD introduction) metal levels were determined from a single homogenized bulk sample, which may not be indicative of pre-leaching metal levels for all increments. Spatial heterogeneity of hydroxyoxide and sulfide formation may also have affected the results to some degree. It is also well known that sequential extraction techniques often result in removal of at least a portion of a given metal fraction in digestions which occur prior to the digestion which is designed to remove the specific metal fraction (ie: part of oxide fraction may be removed during preceding carbonate fraction digestion).

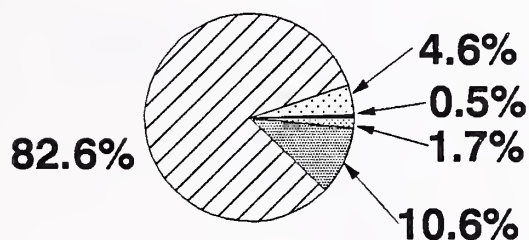
Nonetheless, the degree of sorption or leaching as determined by metal fractionation correlates very closely with metal removal performance as determined by effluent metal concentrations (ie: United Foods mushroom compost had the greatest amount of removed Fe in substrate and the lowest Fe effluent concentrations). This was true for all metals. The fractionation of each metal is discussed in detail below. Percentage values of a given fraction represent the percentage of the total of a given metal which was removed by a given substrate, not the percentage of a metal removed compared to influent concentrations. Where there was no removal (ie: leaching), percent of removal fraction was given a value of 0. Overall total removal values as depicted by pie size in Figures 8 through 10 were determined using removed and leached (-) metal fractions. Relative performance for metal removal in total mg is reported at the beginning of each subsection. Absolute values for removal of Al and Fe were much greater in both mushroom composts than the other substrates while Zn removal and Mn leaching were similar for all substrates.

4.4.1 Aluminum

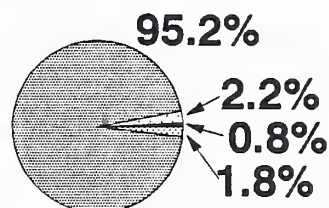
Overall Al sorption/removal in the substrates was in the order United Foods mushroom compost > Great Western mushroom compost >> Peaco peat > Eko-Compost > Groco >> Farmers peat (Figure 8). Metal fractionation results indicate that the majority of Al removed was in the $\text{Na}_4\text{P}_2\text{O}_7$ (organically bound) and EDTA-extractable (carbonate/sulfate) form for all substrates with the exception of Farmers Peat, in which 91 % of Al was in the KNO_3 -extractable (exchangeable) form. The large percentage of Al removal by sorption mechanisms is corroborative with the "breakthrough" behavior noted

ALUMINUM REMOVED

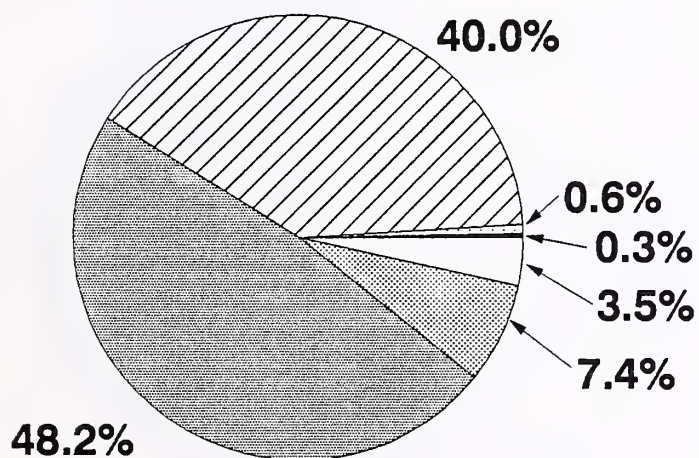
Eko-Kompost



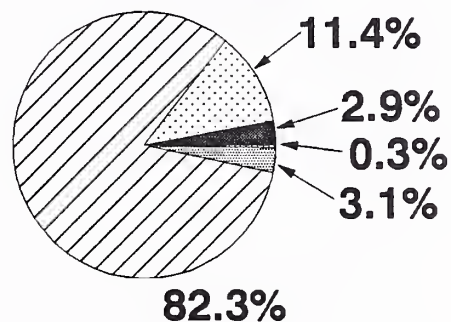
Groco



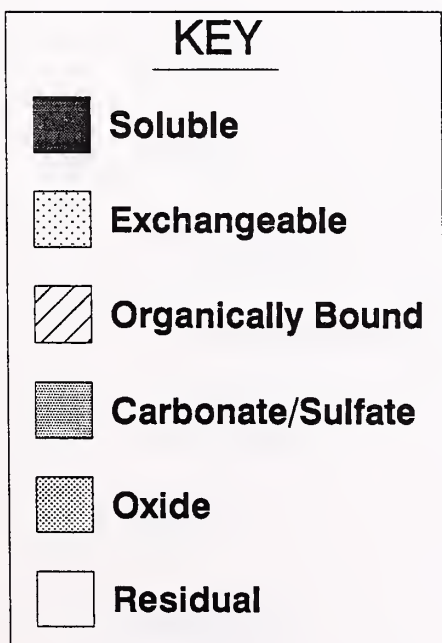
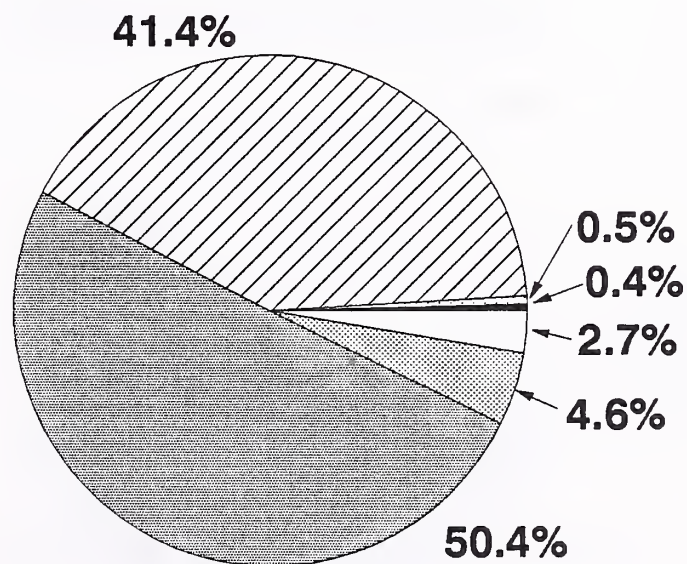
G.W. Mushroom



Peaco Peat



United Foods Mushroom

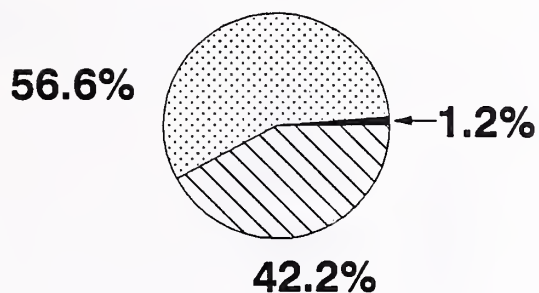


Note: Pie diameter indicates magnitude of total removal.
Farmers Peat was a net Al producer.

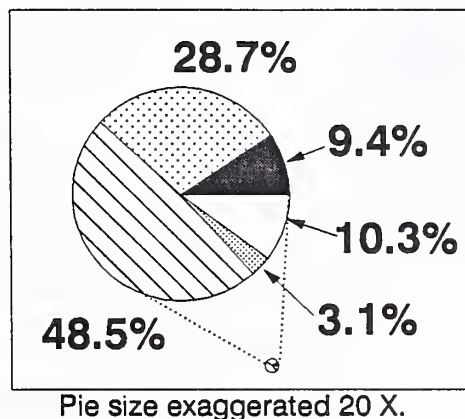
Figure 8. Percentage of total Al removed for each substrate by sorbed and solid fraction.

IRON REMOVED

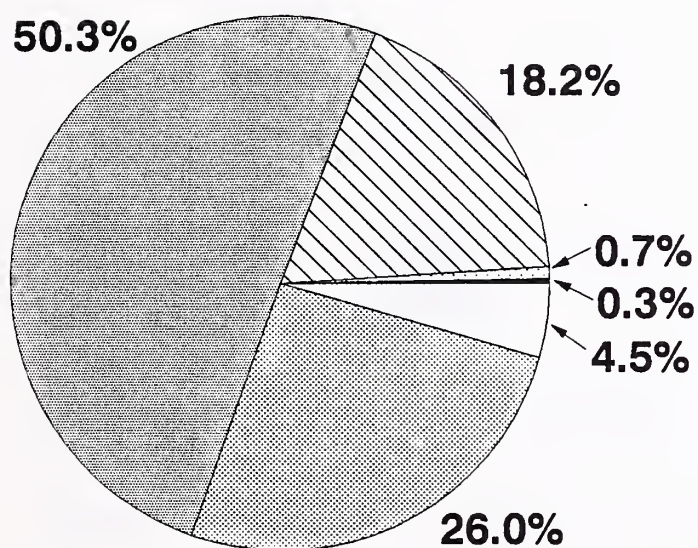
Peaco Peat



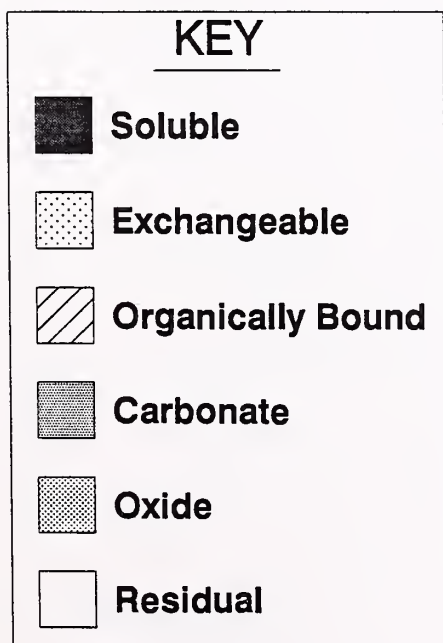
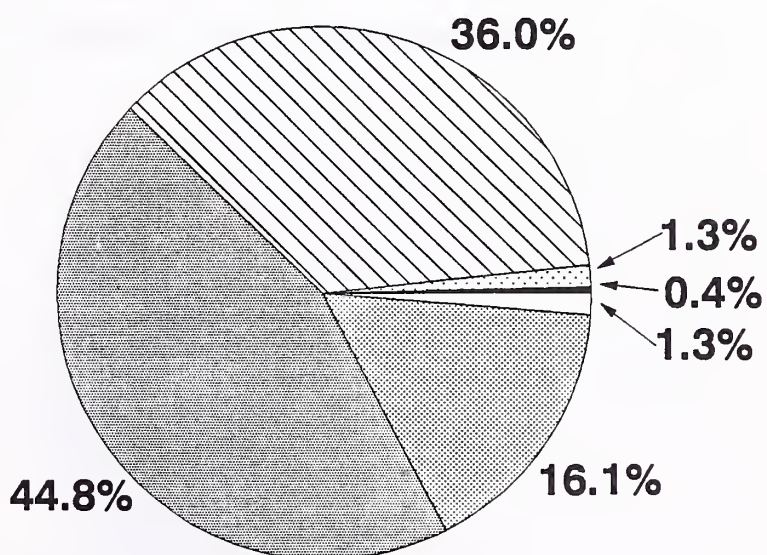
Farmers Peat



G.W. Mushroom



United Foods Mushroom



Note: Pie diameter indicates magnitude of total removal.
Eko Compost and Groco were net Fe producers.

Figure 9. Percentage of total Fe removed for each substrate by sorbed and solid fraction.

ZINC REMOVED

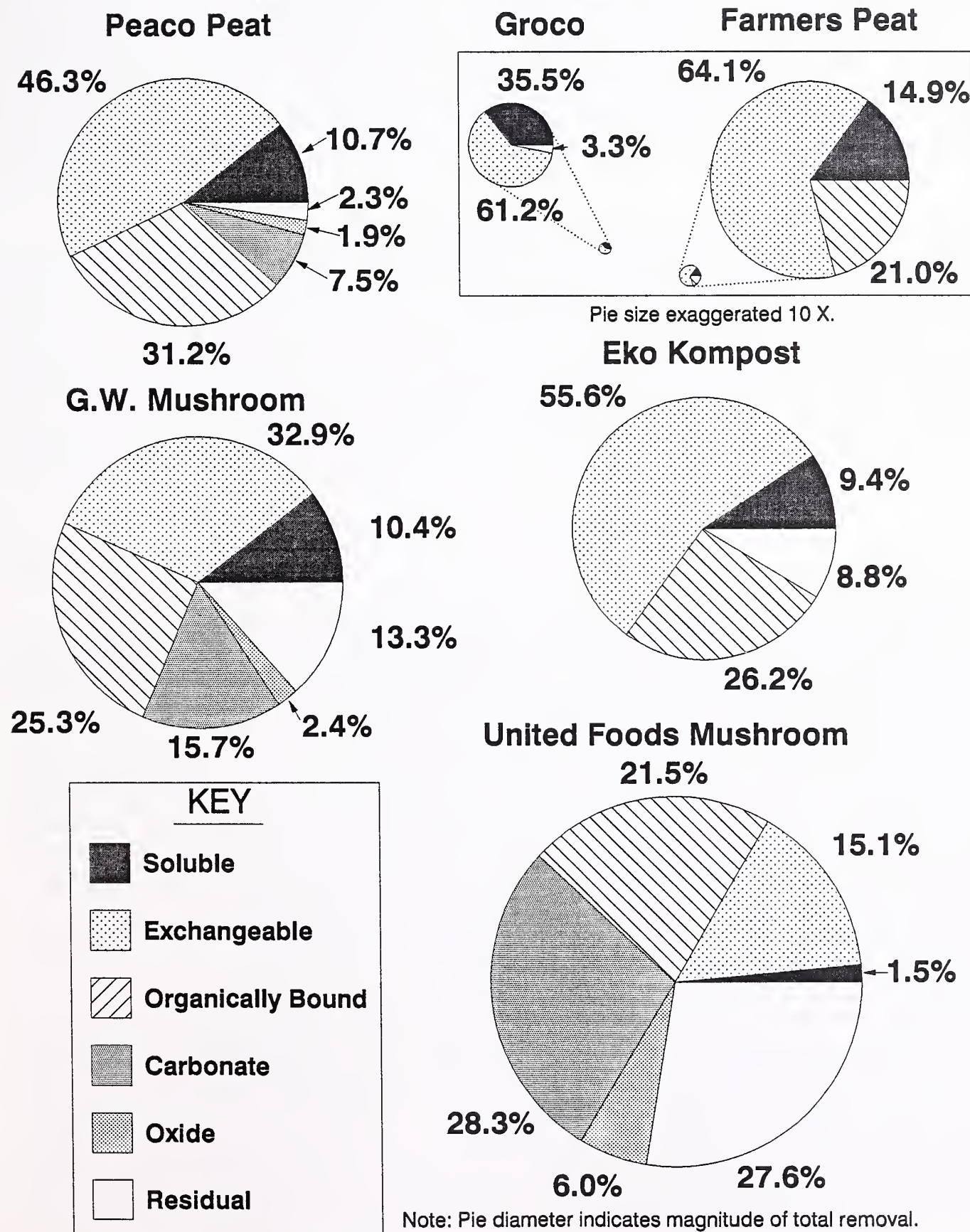


Figure 10. Percentage of total Zn removed for each substrate by sorbed and solid fraction.

in effluent values corresponding to an exhaustion of sorption capacity. Because aluminum carbonate is not known to occur, the EDTA-extractable Al must be derived from some other Al solid phase. Concentration of Al and SO_4 in influent are supersaturated with respect to basic aluminum sulfates, particularly alunite, which is thermodynamically stable in the pH regime of the columns. In addition, thermodynamic data indicate that these minerals would dissolve in the presence of EDTA. Therefore, it is likely that a significant portion of EDTA-extractable Al was derived from basic aluminum sulfates. Part of this fraction of the Al may also be derived from residual Al not extracted in the three prior extractions.

Eko-Compost and Peaco peat both had 82 % Al in the $\text{Na}_4\text{P}_2\text{O}_7$ -extractable form, while Groco had 95 % in the EDTA-extractable form. Significant amounts of Al were also in the $\text{Na}_4\text{P}_2\text{O}_7$ and EDTA-extractable forms in both Great Western and United Foods Mushroom compost (40 % and 41 % and 48 % and 50 %, respectively). DDI-extractable (soluble) Al was < 1 % in all samples except the peats and minor amounts of KNO_3 and $\text{Na}_2\text{S}_2\text{O}_4$ (oxide)-extractable fractions were also present in most substrates. The similarity in metal fractions between the mushroom composts is noteworthy. The low relative percentage of Al as oxides does not corroborate the findings of earlier researchers (Hedin et al 1988, Henrot and Wieder 1990).

4.4.2 Iron

Overall Fe sorption/removal was similar to that of Al and was in the order United Foods mushroom compost > Great Western mushroom compost >> Peaco peat >> Farmers peat > Groco > Eko-Compost (Figure 9). Overall, Groco and Eko-Compost were net Fe producers. Only Eko-Compost showed a significant percentage (> 10 %) of Fe in the DDI-extractable form (40 %) with the remainder in the KNO_3 -extractable fraction. Both Peaco and Farmers peat were the only other substrates with KNO_3 -extractable Fe representing greater than 11 % of total Fe (57 % and 29 %, respectively). A considerable fraction of Fe was present in the $\text{Na}_4\text{P}_2\text{O}_7$ -extractable form in both Great Western and United Foods mushroom compost and Peaco and Farmers peat (18 %, 36% and 42 % and 49 %, respectively). Groco had 84 % Fe present in the EDTA-extractable fraction while this fraction comprised 50 % and 45 % of Great Western and United Foods mushroom compost, respectively. Both FeCO_3 and iron sulfate (jarosite) minerals were thermodynamically favored in the pH range of the mushroom composts, although the net alkalinity and circumneutral pH of the mushroom composts suggest that a majority of this fraction may have been present as FeCO_3 . This fraction, as expected, did not constitute a significant portion of removed Fe in any of the other low pH substrates. Only Great Western and United Foods had appreciable amounts of Fe (26 % and 16 %, respectively) in the $\text{Na}_2\text{S}_2\text{O}_4$ -extractable fraction. As was the case with Al, this value is considerably lower than those typically encountered in the literature. HNO_3 -extractable Fe (residual, assumed to be in part sulfide Fe) was present only in the mushroom composts and Farmers peat. Although this fraction comprised 10 % of the Fe in Farmers peat, the actual quantity of Fe in this form was much less than in Great Western and United Foods (Figure 9). Also, visual

observations corroborate the presence of prevalent "black spots" of FeS formation in the mushroom composts while this was not the case with Farmers peat.

4.4.3 Manganese

No substrate performed as a net Mn remover. Only Great Western and United Foods mushroom compost and Peaco peat showed Mn removal in any fraction. All Mn was in either the DDI, KNO_3 or HNO_3 -extractable fractions, with 29 % and 39 % in the HNO_3 -extractable fraction in the mushroom composts, respectively. The poor removal of Mn is probably due to its tendency to form strong organic complexes at circumneutral pH values (Kabata-Pendias and Kabata 1984) and the need to attain a pH of approximately 8.5 before the formation of Mn hydroxyoxides can occur (Lindsay 1979).

4.4.4 Zinc

Overall Zn sorption/removal in the substrates was in the order United Foods mushroom compost > Great Western mushroom compost > Peaco peat > Eko-Compost >> Farmers peat >> Groco (Figure 10). DDI-extractable Zn accounted for 36 % of all Zn in Groco and between 2 % and 15 % in the other substrates. All substrates had a considerable amount of Zn present in the KNO_3 -extractable fraction, ranging from 64 % and 61 % in Farmers peat and Groco, respectively, to 15 % in United Foods mushroom compost. Both mushroom composts exhibited the most variability in extractable fractions, with 16 % and 28 % as EDTA-extractable Zn and 13 % and 28 % as HNO_3 -extractable Zn for Great Western and United Foods, respectively. This suggests the formation of ZnS , which is thermodynamically more stable than Fe sulfides. The $\text{Na}_2\text{S}_2\text{O}_4$ -extractable Zn fraction was present only in both mushroom composts and Peaco peat between 2% and 6 % of total Zn. These low values agree with thermodynamic data which indicate that influent was undersaturated with respect to common Zn hydroxyoxides. However, Zn may be present as franklinite (ZnFe_2O_4), which is thermodynamically stable in the chemical environment of the columns.

4.5 SUBSTRATE NEUTRALIZATION POTENTIAL

The inherent neutralization potential (NP) of each substrate was determined in an attempt to quantify the role this factor played in the ability of each substrate to neutralize influent acidity. Results are presented below in Table 3 and Figure 11.

It is evident that both mushroom composts have a significantly greater NP than either of the wood waste/sewage sludges or the peats and result in higher equilibrium pH values. Equilibrium pH values and NP are similar for both wood waste/sewage sludges and for Farmers peat. Peaco peat has a slightly higher NP and equilibrium pH value than the aforementioned substrate, but considerably less than the mushroom composts. The inherent neutralization potential was responsible for the circumneutral pH values observed in effluent

Table 3. Substrate pH, neutralization potential and neutralization capacity.

Substrate	Equilibrium pH ¹	Cum Acidity	NP	NC
	Standard Units	----- mg/l -----		liters
Eko-Compost	5.38	140505	56313	55.87
Groco	6.12	122432	47353	46.79
Great Western Mushroom Compost	7.36	121664	247296	240.56
United Foods Mushroom Compost	8.03	126082	187710	184.02
Peaco Peat	4.83	118266	69821	67.79
Farmers Peat	6.34	101439	75429	74.31

¹ - pH value of 5:1 ratio DI water (ml) to substrate (g).

SUBSTRATE NEUTRALIZATION POTENTIAL

Tons CaCO₃/Ton Substrate (x100)

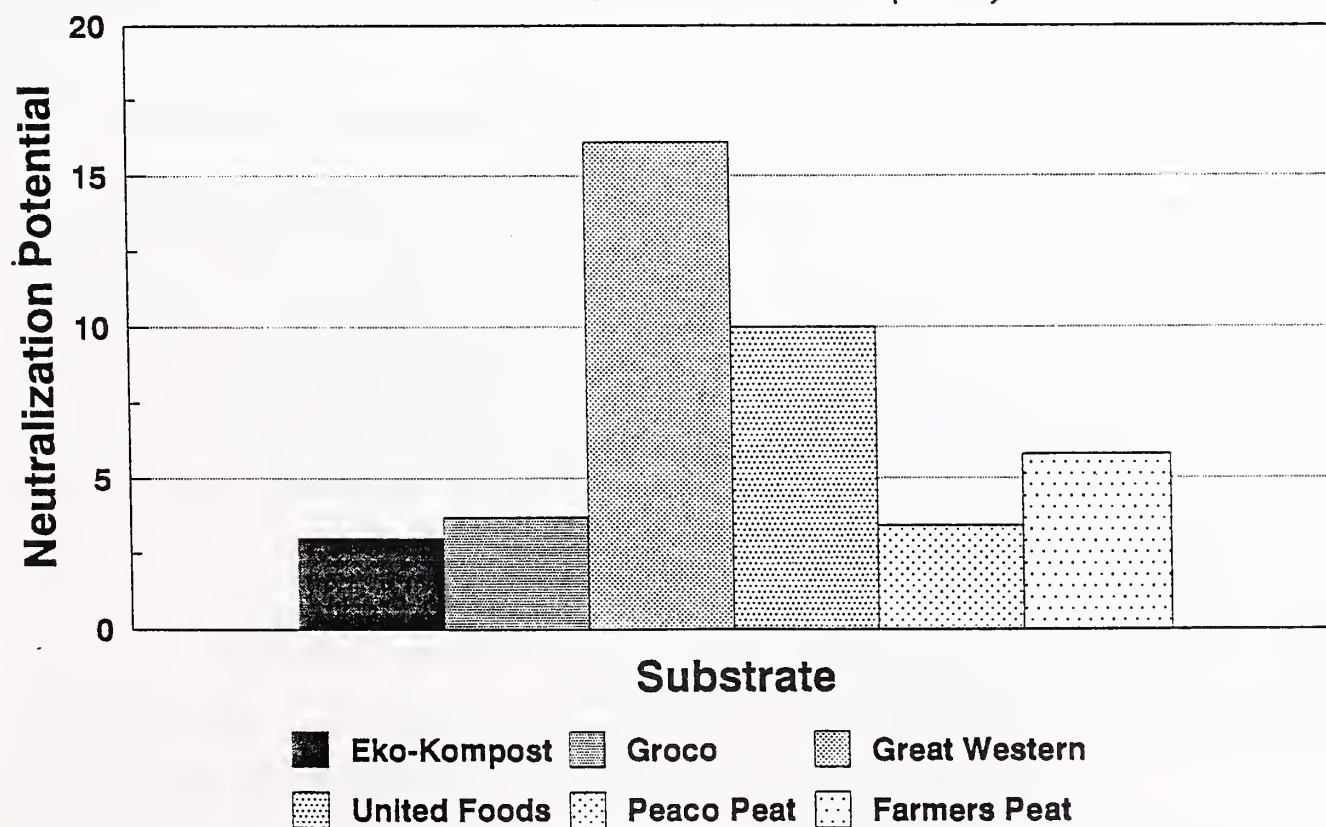


Figure 11. Substrate neutralization potential prior to introduction of AMD.

from all substrates at the start of the study. The possible role of substrate NP in the effectiveness of each substrate as related to effluent chemistry will be elaborated upon further in section 5.0-Discussion.

By determining the mean acidity concentration and the total amount of acidity (as mg/l CaCO_3) in influent which was added to each column, the amount of acidity in AMD which can be neutralized by each column can be determined. This quantity is termed the neutralization capacity (NC) and represents the volume of AMD which can be treated by each column before the NP is exhausted. The following equation was employed to attain these values, which are presented in Table 3. It should be noted that acidity produced within the column by hydrolysis of metals or organic matter is not accounted for and may in part be responsible for the exhaustion of the NP earlier than predicted by equation xx.

$$NC = \left(\frac{NP}{\sum \text{Acidity}} \right) (\sum \text{liters influent AMD}) \quad [3]$$

The NC values in Table 3 indicate that both mushroom composts had excess NP remaining at the end of the study, suggesting a large part of the neutralization of acidity may be attributed to the inherent NP. Although alkalinity was certainly produced by microbial action as evidenced by the addition of sodium lactate, it is not possible to determine to what degree each source of alkalinity is responsible for acid neutralization. It is probable that the decline in pH and concomitant breakthrough in metals was contemporaneous with the exhaustion of the NP and exchange capacity of the peats and wood waste/sewage sludges.

4.6 HYDRAULIC CONDUCTIVITY

Saturated hydraulic conductivity (K) values measured at various times throughout the study are presented in Figure 15. Values were recorded after periods of steady flow rate. The K value for Eko-Compost is approximately an order of magnitude greater than the other substrates, which are all within an order of magnitude. This was not true of the uncompacted K values determined prior to column testing. No significant ($> 1 \times 10^{-1}$) changes occurred throughout the period of measurement. It should be noted, however, that considerable variation on a daily to weekly basis was observed indirectly by the necessity to make frequent adjustments to the Mariotte device (head) to maintain an approximate constant flow rate. The sensitivity of the substrates to small changes in head was also noticed, as was a "threshold" effect. It was often necessary to increase the head several (10 to 20) cm to produce a noticeable change in flow rate. The resultant flow rate was sometimes a significant increase over the small change desired and the head was then "backed-off" to a lower level to achieve the desired rate. The similarity in K between substrates may in part be due to the compaction of each substrate to 4.5 psi at the start of the study, although differences in swelling likely affected substrate K.

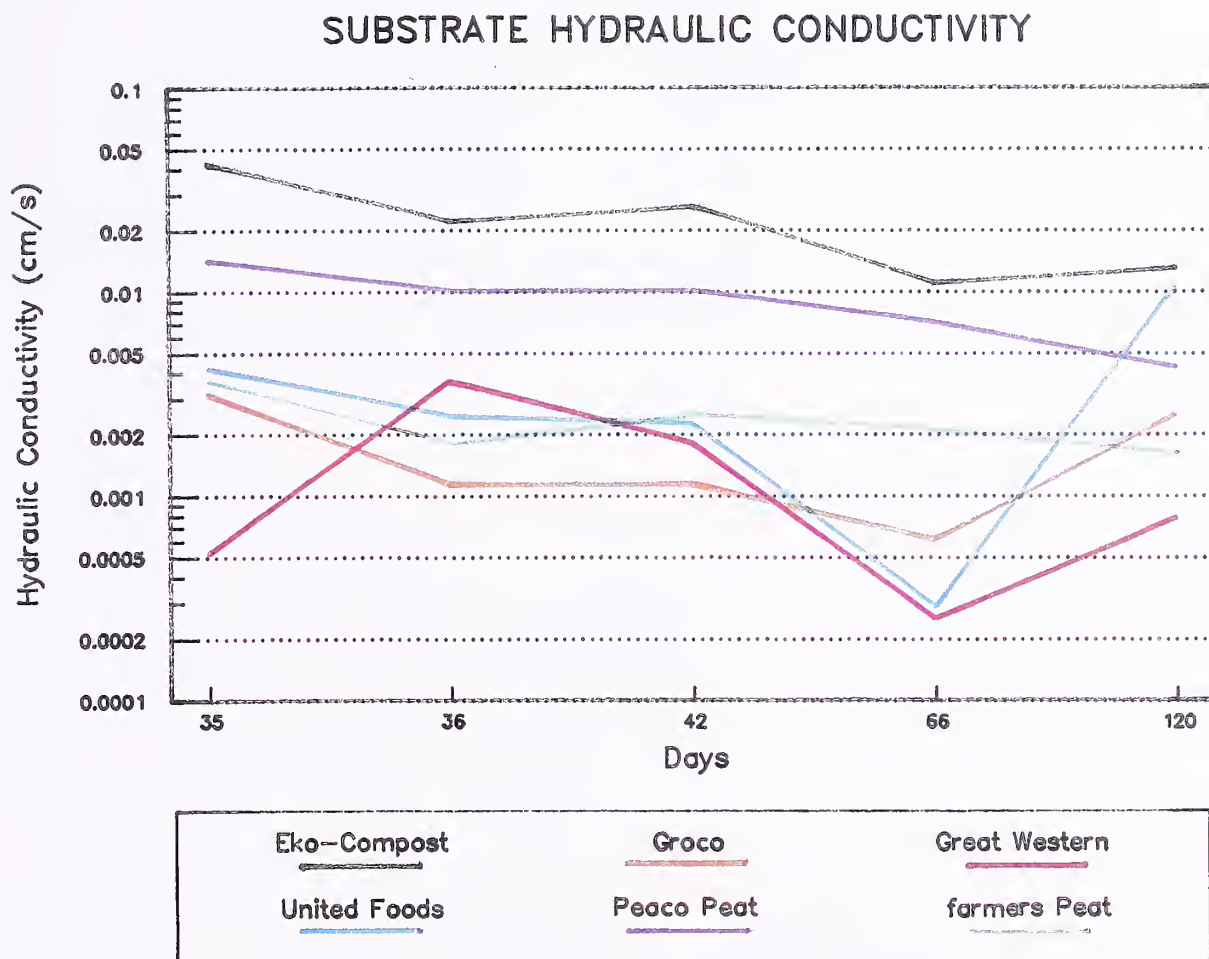


Figure 12. Substrate saturated hydraulic conductivity values through time during study.

4.7 OBSERVATIONS

The following summary of visual observations will address primarily the timing and nature of precipitates which were formed and the development of FeS "black spots". Effluent visual characteristics will also be discussed. Following the introduction of AMD into the columns, effluent waters were typically murky and filled with suspended colloids of what appeared to be Fe hydroxyoxides. It is likely that Al hydroxyoxides and gypsum were also present. Effluent water from the mushroom composts did not exhibit the milky orange/yellow to cream color of the other effluents but rather was organic-rich, foul-smelling and deep tea-brown in color. Precipitates first began to form in the gravels at the base of the columns after approximately 11 days in all columns with the exception of column 1 (Eko-Compost). Through time, these precipitates spread throughout the gravel and into the bottom few centimeters of substrate. Some of these precipitates were originally a light yellow to orange in color but became darker orange with time and were presumed to be Fe and possibly Al hydroxyoxides. Fouling was initially strongest in both mushroom composts, most likely due to their high alkalinity, and very slight in Eko-Compost and Farmers peat. By day 46 of the study, effluent water from the mushroom composts had more or less

cleared and was a slightly murky orange, while effluents from the other substrates also began to clear. Fouling in the lower part of the columns continued throughout the study period and was strongest in the mushroom composts and Peaco peat, moving approximately 18 cm into the substrate in the former. A milky cream colored, amorphous precipitate also formed on the top of the substrate in columns 1 and 2. Similar precipitates were noted in a wetland constructed to treat AMD in Pennsylvania (Hedin et al 1988) and by the authors at AMD sites throughout Cascade County, Montana.. This precipitate was also common in voids which formed when the substrate separated in lifts. Flakey white precipitates were common in columns 3 through 5 and were most likely gypsum. Precipitation of orange hydroxyoxides occurred at the top of Farmers peat.

By day 35 of the study "black spots" (presumed to be FeS) began to develop in the bottom 10 cm of column 3 (Great Western mushroom compost) and were observed between 18 cm and 25 cm in column 4 (United Foods mushroom compost) by day 46. A single, small spot (1 cm) at 38 cm also developed in column 2 (Groco) at this time. As time passed, the number and size of the black spots grew in columns 3 and 4, often forming semicontinuous bands. Formation of the FeS was accompanied by a very strong H₂S smell that required active venting of the study area. The great majority of H₂S was derived from columns 3 and 4. Darker (but not black) bands were also observed in the bottom of columns 1, 5 and 6, but probably were due to density disparities as a result of initial compaction and were too uniform in shape to be FeS.

The last effluent was collected on day 233 and the introduction of influent was discontinued at this time. Substrate was removed from the columns for sampling on day 242. By this time, a distinct black band had formed between 38 and 47 cm in column 2 but was not continuous throughout this sampling interval. This band correlated to a pore water pH value of 5.17, more than 1.65 units greater than any other reading in the column, and suggests the production of alkalinity associated with microbial SO₄ reduction. A dark band between 25 cm and 35 cm and heavy FeS mottling in the lower 25 cm of column 3 was prevalent. Discontinuous stringers and mottles were common (60 % of visible area) throughout the upper 51 cm of column 4, being particularly dense between 30 cm and 47 cm. Although there was no readily visible evidence of FeS formation in columns 1, 5 and 6, all columns produced a strong H₂S smell while being broken down. This observation, in conjunction with port sampling data showing the presence of dissolved S²⁻, indicates that sulfate reduction was occurring in at least some degree in all columns.

5.0 DISCUSSION

This section will focus on relative performance of the substrates, implied mechanisms of metal removal and acid/alkaline production and the bearing these factors have in the use of wetlands.

Effluent chemistry results indicate that only the mushroom composts were effective at treating metals, with the exception of Mn, and maintaining circumneutral pH values. The composted sewage sludge/wood wastes and peats did not consistently depress metal levels or maintain a neutral pH. Initially all substrates removed metals and produced neutral effluent pH values due to the cation exchange capacity and inherent NP of the substrates. However, as these exchange sites filled and the NP was exhausted, a rise in metal levels was observed with a concomitant decrease in pH values. The removal of Al and Fe by sorption mechanisms in wood waste/sewage sludges and peats is corroborated by the substrate fractionation data. This phenomenon occurred fairly rapidly in the wood waste/sewage sludges and peats, with Fe generally showing a breakthrough before Al. In some cases, Fe and Al concentrations exceeded those of influent values. This may have been the result of colloidal Fe and Al precipitates which were present in filtered effluent and solubilized upon acidification (preservation) or the solubilization of Al and Fe hydroxyoxides as effluent pH values declined.

Results from the port samples showed a decrease in Eh with distance from the influent port, as expected. Henrot and Weider (1990) has noted that below a depth of approximately 20 cm, O_2 levels are near 0 and Eh values are typically negative. This phenomenon would obviously be affected by flow rate. Therefore, a 20 cm depth of substrate is adequate to achieve reducing conditions and for growth of cattails. Any depths in excess of this value would simply provide more organic matter and exchange and NP capacity. Given the desired long-term life of a wetland, the extra exchange capacity gained by increased depths would not be significant. However, depth in excess of 20 cm would provide a larger zone (greater volume) in which SO_4 reduction can occur and an initially greater food source for microbes. However, a greater amount of available organic matter would likely result in a larger magnitude of SO_4 reduction and not necessarily support a given rate of reduction for longer periods of time. Ultimately, the stable supply of requisite macronutrients (C and N) must come from recycling and decomposition of wetland vegetation or by periodic supplemental fertilization.

Depth solution samples showed that in the effective substrates (mushroom composts) pH levels did not reach a near neutral value until the top (33cm) of the substrate. It is not known if these pH values were strictly a function of SO_4 reduction occurring in these zones or if pH values dropped in the lower zones as NP was consumed at a rate fast enough such that pH was inhibitory to SO_4 reduction. Results from the NP determination indicate that both mushroom composts still had inherent NP remaining at the end of the study. It is

therefore difficult to determine to what degree alkalinity produced through SO_4 reduction was responsible for the performance of the mushroom composts. It is possible that NP in the uppermost substrate may still have been present at the end of the study and may have maintained pH values high enough and for long enough to allow SO_4 reducing microbes to reach a stable population. If this was the case, then it is possible that a depth of <33 cm would have resulted in little SO_4 reduction. Also, this would imply that the introduction of alkalinity into the system prior to AMD entering the wetland (ie: anoxic alkaline trench) may provide an environment where sulfate reduction can occur at an optimum rate, assuming adequate C, N and other nutrients were available.

The addition of lactate indicated that a readily available supply of C was not the limiting factor to SO_4 reduction in the wood waste/sewage sludges and peats. It is possible that N was limiting in these substrates and by inference, not limiting in the mushroom composts, as evidenced by the increased activity in SO_4 reduction with the addition of lactate as measured by alkalinity. It is not known if the addition of lactate at an earlier date when pH values were higher and more conducive to SO_4 reduction would have wrought a different response.

The role of residence time as determined by influent flow rate, substrate thickness and K_s , obviously plays an important role in determining the effectiveness of a wetland. The role of substrate thickness has already been discussed. In this study, mean flow rate was maintained at approximately 0.5 l/d. With a pore volume equivalent of approximately 5 l, the residence time was approximately 10 days. Slower flow rates were unstable with the apparatus used in this study. It is possible that a longer residence time would improve the performance of the substrate, especially the composted sewage sludge/wood wastes and peats, but the data suggest that conditions were not conducive to SO_4 reduction and thus increased residence time likely would not have a great effect on performance.

6.0 CONCLUSIONS

In summary, a review of AMD treatment response in each of the columns suggests that a number of biological, chemical and physical processes account for metal removal and reduction in acidity:

- Initially, all organic-substrates provided excellent metal removal and limited to excellent pH control due to adsorption of metals and inherent neutralization capacities, respectively. Saturation of substrate exchange capacity, however, occurs within weeks. Only the mushroom composts maintained circumneutral pH values throughout the study, due in part to their greater relative inherent neutralization potentials, which were not depleted through the course of the study. The mushroom composts also removed > 99 % of influent Al and Fe and all substrates provided > 99 % removal of influent Zn throughout the study. All substrates were net Mn producers.
- The primary mechanisms of metal removal were adsorption (both specific and non-specific) and precipitation of carbonates, sulfates and to a lesser degree hydroxyoxides. Precipitation of metal sulfides appeared to be kinetically limited.
- Very limited sulfate reduction occurred in acidic substrates (wood waste/sewage sludges and peats); alkaline conditions are required for sulfate-reducing bacteria.
- A residence time of at least several days is required before microbial populations can bring about reduction of the primary electron acceptors in AMD. These include dissolved oxygen and nitrate.
- Most iron was removed as a carbonate (siderite) in the mushroom composts. The inherent neutralizing capacity of substrate and the alkalinity produced by sulfate-reducing bacteria may both contribute to the precipitation of siderite. In addition, reducing conditions may help maintain Fe^{2+} as the dominant iron form in solution, an apparent prerequisite to precipitation of iron carbonate.
- Long-term effectiveness of non-oxidizing wetland systems will depend upon a continued supply of readily-decomposable organic carbon that can be metabolized by heterogeneous microbial communities that produce simple organic acids and alcohols, the primary food source for sulfate-reducing bacteria. Adequate supply of primary nutrients, especially nitrogen, is also expected to be a prerequisite for AMD treatment.

- Hydraulic conductivities ranged between 1.39×10^{-3} to 2.28×10^{-2} cm/s. Flow was sufficiently maintained throughout the experiment at low (30cm) head values. Continued precipitation of metals may ultimately plug primary flow paths, however, leading to "short-circuiting" of flow through the substrate and poorer AMD treatment. Such breakthrough or an exhaustion of the microbial food supply is a signal that organic and nutrient cycling is inadequate. Supplemental fertilization or substrate removal and replacement may be necessary in such cases.

7.0 LITERATURE CITED

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APPENDIX A

COLUMN INFLUENT AND EFFLUENT CHEMISTRY

EKO-KOMPOST COMPOSTED SLUDGE/WOOD WASTE

EKO-KOMPOST COMPOSTED SLUDGE/WOOD WASTE

GROCO COMPOSTED SLUDGE

Influent/ Effluent Sample	DATE SAMPLED	ELAPSED TIME (DAYS)	LEACHATE PORE VOLUMES	pH	Elec. Cond. (mmhos/ cm)	ORP (mv)	TITRAT. ACID. (mg/L)	TDS (mg/ L)	ALK. (mg/ L)	SO4 (mg/ L)	TOTAL ORG. C (mg/L)	TOTAL DISS. Fe (mg/L)	DISS. FERRIC Fe (mg/L)	DISS. FERROUS Fe (mg/L)	DISS. Al (mg/L)	DISS. Mn (mg/L)	DISS. Zn (mg/L)	DISS. Ca (mg/ L)	DISS. Mg (mg/ L)	
Influent	04/18/90	12	.5	2.8	2.45	-	1070	2270	-	1720	-	108.00	-	-	89.00	-	-	3.52	-	-
Effluent	04/17/90	11	0	6.7	3.88	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Effluent	04/24/90	18	.5	7.1	2.71	517	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Effluent	04/27/90	21	1	7.1	3.61	309	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Effluent	05/07/90	31	2	7.0	3.44	330	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Influent	05/09/90	33	2	2.8	2.45	-	1060	2420	-	1570	-	122.00	-	-	98.00	0.40	3.01	155.0	70.0	-
Effluent	05/11/90	35	2	6.6	2.76	364	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Effluent	05/15/90	39	3	-	-	-	-	2150	106	1330	14.0	0.40	0.40	-	-	3.55	-	-	-	-
Effluent	05/18/90	42	3	6.9	2.01	358	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Effluent	06/22/90	77	7	6.2	-	357	1460	2120	-	1440	-	36.40	-	-	88.70	7.52	0.02	-	-	-
Influent	06/25/90	80	7	2.8	2.45	-	980	2820	-	1550	-	85.70	85.10	0.62	-	0.37	2.71	-	-	-
Effluent	06/28/90	83	8	5.9	2.08	388	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Influent	07/02/90	87	9	2.8	2.45	-	961	2570	-	1570	-	85.70	85.10	0.60	90.90	0.38	2.86	-	-	-
Effluent	07/05/90	90	8	-	-	-	165	2270	-	1400	4.0	115.00	-	115.00	-	7.64	0.03	-	-	-
Effluent	08/01/90	117	12	5.3	2.21	295	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Influent	08/08/90	124	15	2.8	2.45	-	1010	2670	-	1720	-	94.00	94.00	-	93.90	-	2.65	-	-	-
Effluent	08/08/90	124	15	3.9	-	323	492	2310	-	1610	4.0	220.00	138.00	82.00	5.00	6.45	-	-	-	-
Effluent	08/23/90	139	17	3.8	1.95	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Effluent	08/24/90	140	17	3.5	2.57	334	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Influent	08/27/90	143	17	-	-	-	993	2630	-	1710	-	99.40	-	-	99.90	-	2.83	-	-	-
Influent	09/07/90	154	18	2.6	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Effluent	09/07/90	154	18	3.1	2.80	750	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Effluent	09/08/90	155	18	-	-	-	652	2410	0	1540	5.0	98.00	70.0	28.0	45.20	2.51	0.0	-	-	-
Effluent	09/16/90	163	18	-	-	-	68	2390	0	1560	7.0	100.0	99.2	0.8	59.1	1.62	0.0	-	-	-
Effluent	09/18/90	165	18	2.7	2.00	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Effluent	09/19/90	166	18	3.2	2.30	606	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Influent	10/29/90	206	19	-	-	-	582	5430	0	1790	-	92.9	-	-	90.7	-	2.62	-	-	-
Influent	10/30/90	207	19	3.5	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Effluent	11/05/90	213	19	4.0	3.58	559	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Effluent	11/13/90	221	20	3.9	3.05	603	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Effluent	11/16/90	224	21	4.0	3.61	572	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Effluent	11/21/90	229	21	-	-	-	699	4540	-	<1	1100	97.4	0.0	97.4	149.0	0.25	4.57	-	-	-
Effluent	11/26/90	234	22	4.2	3.41	611	-	-	-	-	-	-	-	-	-	-	-	-	-	-

GREAT WESTERN MUSHROOM COMPOST

[illegible]

WETI AND SUBSTRATE COLUMN

Influent/ Effluent Sample	DATE SAMPLED	ELAPSED TIME (DAYS)	LEACHATE PORE VOLUMES	pH	Elec. Cond. (mmhos/ cm)	ORP (mv)	TITRAT. ACID. (mg/L)	TDS (mg/ L)	ALK. (mg/ L)	SO4 (mg/ L)	TOTAL ORG. C (mg/L)	TOTAL DISS. Fe (mg/L)	DISS. FERRIC Fe (mg/L)	DISS. FERROUS Fe (mg/L)	DISS. AL (mg/L)	DISS. Mn (mg/L)	DISS. Zn (mg/L)	DISS. Ca (mg/ L)	DISS. Mg (mg/ L)	
Influent	04/10/90	4	.5	2.8	2.45	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Effluent	04/17/90	11	.5	6.0	20.00	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Effluent	04/24/90	18	.5	6.7	20.00	94	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Effluent	04/27/90	21	1	6.9	20.00	137	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Effluent	05/07/90	31	2	6.6	20.00	220	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Influent	05/09/90	33	2	2.8	2.45	-	1060	2580	-	1570	-	106.00	-	-	97.00	0.40	3.03	155.0	69.0	-
Effluent	05/11/90	35	2	5.8	20.00	283	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Influent	05/14/90	38	2	2.8	2.45	-	-	-	-	-	-	102.00	-	-	102.00	0.40	2.86	159.0	67.0	-
Effluent	05/18/90	42	3	6.3	3.04	298	-	5350	420	1940	570.00	4.10	1.30	2.80	0.30	1.20	0.21	-	-	-
Influent	06/11/90	66	3	2.8	2.45	-	-	-	-	-	-	91.80	-	-	92.20	0.38	2.78	147.0	68.0	-
Effluent	06/22/90	77	8	6.5	2.45	215	-	4430	1740	1640	-	0.05	-	-	0.10	0.64	0.01	-	-	-
Effluent	06/28/90	83	9	7.2	5.05	150	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Influent	07/02/90	87	10	2.8	2.45	-	1000	2620	-	1650	2.00	91.80	90.70	1.10	97.20	0.40	2.93	-	-	-
Effluent	07/12/90	97	10	2.8	2.45	-	-	4160	1250	1800	70.00	0.06	0.06	0.10	0.10	0.47	0.03	-	-	-
Effluent	08/01/90	117	11	6.5	3.50	133	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Effluent	08/08/90	124	14	6.0	2.45	222	-	3470	167	2260	16.00	3.00	0.30	2.70	0.10	2.30	0.02	-	-	-
Influent	08/08/90	124	12	2.8	2.45	-	1020	2770	-	1760	2.00	92.00	92.00	0.20	90.70	0.02	2.62	-	-	-
Effluent	08/23/90	139	17	6.7	2.58	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Effluent	08/24/90	140	17	6.0	3.12	257	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Effluent	08/30/90	146	18	7.0	2.62	253	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Influent	09/07/90	154	17	2.6	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Effluent	09/07/90	154	18	5.9	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Effluent	09/07/90	154	18	6.2	3.34	198	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Effluent	09/08/90	154	18	-	-	-	0	3310	237	1980	19.0	0.7	0.0	0.7	0.0	2.16	0.0	-	-	-
Influent	09/14/90	161	17	-	-	-	1040	2520	-	1730	-	106.0	-	-	102.0	0.0	3.11	-	-	-
Effluent	09/15/90	162	19	-	-	-	0	3380	193	2040	18.0	1.4	1.2	0.2	0.0	2.8	0.03	-	-	-
Effluent	09/18/90	165	20	6.0	3.23	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Effluent	09/19/90	166	20	6.4	3.33	245	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Influent	10/29/90	206	22	-	-	-	235	8440	0	1750	-	91.7	-	-	88.1	0.0	2.58	-	-	-
Influent	10/30/90	207	22	4.5	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Effluent	11/05/90	213	21	6.3	3.05	320	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Effluent	11/13/90	221	22	6.6	3.85	289	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Effluent	11/16/90	224	23	6.3	5.87	228	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Effluent	11/21/90	229	23	-	-	-	<1	8160	2700	2840	1270	0.3	0.1	0.2	0.4	1.91	0.0	-	-	-
Effluent	11/26/90	234	24	6.6	5.15	169	-	-	-	-	-	-	-	-	-	-	-	-	-	-

PEACO PEAT MOSS

[illegible]

FARMER'S PEAT MOSS

[illegible]

The following tables of this appendix contain data regarding the N concentration in column influents and effluents. All other information in the tables is identical to that presented in the previous tables of this appendix.

COLUMN STUDY --- INFLUENT CHEMISTRY
COLUMN 1 - EKO-COMPOST

DATE	ELAP DAYS	PORE VOL ²	pH	EC	ACID. (mg/L)	ALK. (mg/L)	SULFATE (mg/L)	NITRATE (mg/L) ³	TDS (mg/L)	ORGANIC CARBON (mg/L)
04/18/90	12	.5	2.75	2.45	1010	1	1620	0.05	2440	2
05/09/90	33	2	-	-	1020	-	1500	-	2620	-
05/11/90	35	5	-	-	1050	-	1600	-	2490	-
05/16/90	40	7	2.75	2.45	1160	-	1600	0.05	2470	2
06/11/90	66	10	-	-	784	-	1570	-	-	-
06/25/90	80	13	-	-	973	-	1550	-	2860	-
07/30/90	115	15	-	-	973	-	1550	-	2860	-
08/08/90	124	18	2.75	2.45	1050	-	1720	-	2730	2
08/17/90	133	20	-	-	-	-	-	-	-	-
09/07/90	154	22	2.55	-	-	-	-	-	-	-
09/12/90	159	23	-	-	1020	-	1710	-	2420	-
10/29/90 ¹	206	25	-	-	613	-	1780	-	5220	-
11/09/90 ¹	217	26	-	-	-	-	-	-	-	-

¹ Influent following the addition of lactate.

² Pore volume represents AMD entering column plus carboy storage volume.

³ Nitrogen reported as nitrate-N.

COLUMN STUDY --- EFFLUENT CHEMISTRY
COLUMN 1 - EKO-COMPOST

DATE	ELAP DAYS	PORE VOL	pH	EC	ORP (mv)	PE	ACID. (mg/L)	ALK. (mg/L)	SULFATE (mg/L)	NITROGEN (mg/L) ²	TDS (mg/L)	ORGANIC CARBON (mg/L)
04/17/90	11	.5	5.16	2.90	0	-	-	-	-	-	-	-
04/24/90	18	.5	6.11	2.22	624	11	-	-	-	-	-	-
04/27/90	21	1	6.37	2.06	375	6	-	-	-	-	-	-
05/07/90	31	2	6.46	2.55	463	8	-	-	-	-	-	-
05/11/90	35	5	6.81	2.32	471	8	-	-	-	-	-	-
05/15/90	39	7	0.00	0.00	-	-	-	79	1500	0.10	3810	15
05/18/90	42	8	7.41	1.88	457	8	-	-	-	-	-	-
06/22/90	77	12	6.34	0.00	362	6	6220	-	1450	-	2060	-
06/28/90	83	13	5.82	2.12	399	7	-	-	-	-	-	-
07/02/90	87	14	0.00	0.00	-	-	252	-	1480	-	2360	6
08/01/90	117	16	5.45	1.86	266	5	-	-	1600	-	2330	5
08/06/90	122	18	0.00	0.00	-	-	-	-	-	-	-	-
08/23/90	139	21	4.08	2.22	-	-	-	-	-	-	-	-
08/24/90	140	21	4.67	2.24	-	-	-	-	-	-	-	-
08/30/90	146	23	4.31	2.10	283	5	-	-	-	-	-	-
09/07/90	154	23	4.09	2.98	473	8	-	-	-	-	-	-
09/07/90	154	23	2.92	0.00	-	-	-	-	-	-	-	-
09/08/90	155	23	0.00	0.00	-	-	597	-	1570	<.05	2280	7
09/16/90	163	24	0.00	0.00	-	-	762	-	1640	<.05	2360	9
09/18/90	165	24	3.05	2.10	-	-	-	-	-	-	-	-
09/19/90	166	25	3.81	2.15	535	9	-	-	-	-	-	-
10/30/90 ¹	207	25	3.50	0.00	-	-	-	-	-	-	-	-
11/05/90 ¹	213	25	3.84	2.36	536	9	-	-	-	-	-	-
11/13/90 ¹	221	26	3.93	3.13	500	8	-	-	-	-	-	-
11/16/90 ¹	224	27	4.10	3.64	510	9	-	-	-	-	-	-
11/21/90 ¹	229	27	0.00	0.00	-	-	991	<1	1900	10.2	4750	690
11/26/90 ¹	233	28	4.25	3.13	508	9	-	-	-	-	-	-

¹ Effluent following the addition of lactate.

² Nitrogen reported as nitrate-N through day 160. Reported as TKN following day 160.

COLUMN STUDY --- INFLUENT
COLUMN 2 - GROCO

DATE	ELAP DAYS	PORE VOL ²	pH	EC	ORP (mv)	ACID. (mg/L)	ALK. (mg/L)	SULFATE (mg/L)	NITRATE (mg/L) ³	TDS (mg/L)	ORGANIC CARBON (mg/L)
04/18/90	12	.5	2.75	2.45	-	1070	-	-	<1	1720	<0.05
05/09/90	33	2	2.75	2.45	-	1060	1570	2420	-	-	-
05/25/90	49	5	-	-	-	-	-	-	-	-	-
06/25/90	80	7	2.75	2.45	-	980	1550	2820	-	-	-
07/02/90	87	9	2.75	2.45	-	961	1570	2570	<2	-	-
07/30/90	115	12	-	-	-	-	-	-	-	-	-
08/06/90	124	15	2.75	2.45	-	1010	1720	2670	<2	-	-
08/27/90	143	17	-	-	-	993	1710	2630	-	-	-
09/07/90	154	18	2.64	-	-	-	-	-	-	-	-
10/29/90 ¹	206	19	-	-	-	-	582	1790	5430	-	-
10/30/90 ¹	207	19	3.58	-	-	-	-	-	-	-	-

¹ Influent following the addition of lactate.

² Pore volume represents AMD entering column plus carboy storage.

³ Nitrogen reported as nitrate-N.

COLUMN STUDY --- EFFLUENT CHEMISTRY
COLUMN 2 - GROCO

DATE	ELAP DAYS	PORE VOL	pH	EC (mv)	ORP	ACID. (mg/L)	ALK. (mg/L)	SULFATE (mg/L)	NITROGEN (mg/L)	TDS (mg/L)	ORGANIC CARBON (mg/L)
04/17/90	11	0	6.70	3.88	-	-	-	-	-	-	-
04/24/90	18	.5	7.07	2.71	517	-	-	-	-	-	-
04/27/90	21	1	7.13	3.61	309	-	-	-	-	-	-
05/07/90	31	2	6.99	3.44	330	-	-	-	-	-	-
05/11/90	35	2	6.59	2.76	364	-	-	-	-	-	-
05/15/90	39	3	-	-	-	106	-	1330	<.05	2150	14
05/18/90	42	3	6.90	2.01	358	-	-	-	-	-	-
06/22/90	77	7	6.23	3.57	-	1460	-	1440	-	2120	-
06/28/90	83	8	5.93	2.08	388	-	-	-	-	-	-
07/05/90	90	8	-	-	-	165	-	1400	-	2270	4
08/01/90	117	12	5.34	2.21	295	-	-	-	-	-	-
08/08/90	124	15	3.85	-	323	492	-	1610	-	2310	4
08/23/90	139	17	3.79	1.95	-	-	-	-	-	-	-
08/24/90	140	17	3.47	2.57	334	-	-	-	-	-	-
09/07/90	154	18	2.84	-	-	-	-	-	-	-	-
09/07/90	154	18	3.17	2.80	750	-	-	-	-	-	-
09/08/90	155	18	-	-	-	652	-	1540	<.05	2410	5
09/16/90	163	18	-	-	-	68	-	1560	<.05	2390	7
09/18/90	165	18	2.72	2.00	-	-	-	-	-	-	-
09/19/90	166	18	3.26	2.30	606	-	-	-	-	-	-
11/05/90 ¹	213	19	4.05	3.58	559	-	-	-	-	-	-
11/13/90 ¹	216	20	3.98	3.05	603	-	-	-	-	-	-
11/16/90 ¹	218	21	4.08	3.61	572	-	-	-	-	-	-
11/26/90 ¹	228	22	4.25	3.41	611	-	-	-	-	-	-

¹ Effluent following the addition of lactate.

² Nitrogen reported as nitrate-N through day 160. Reported as TKN following day 160.

COLUMN STUDY --- INFLUENT CHEMISTRY
COLUMN 3 - GREAT WESTERN MUSHROOM COMPOST

DATE	ELAP DAYS	PORE VOL ³	pH	EC (mv)	ORP (mg/L)	ACID. (mg/L)	ALK. (mg/L)	SULFATE (mg/L)	NITRATE (mg/L) ³	TDS (mg/L)	ORGANIC CARBON (mg/L)
04/18/90	12	.5	2.75	2.45	-	1050	-	1720	.05	2290	2
05/09/90	33	2	-	-	-	1080	-	1560	-	2550	-
05/18/90	42	3	-	-	-	-	-	-	-	-	-
06/11/90	66	7	-	-	-	-	-	-	-	-	-
07/03/90	88	10	-	-	-	969	-	191	-	2670	2
08/06/90	122	15	-	-	-	-	-	-	-	-	-
08/08/90	124	15	2.75	2.45	-	1020	-	1740	-	2640	2
08/18/90	134	17	-	-	-	-	-	-	-	-	-
08/27/90	143	18	-	-	-	-	-	1020	-	1730	-
09/07/90	154	19	2.66	-	-	-	-	-	-	-	-
09/12/90	159	19	-	-	-	-	-	1030	-	1700	-
10/29/90 ¹	206	20	-	-	-	-	-	592	-	1780	-
10/30/90 ¹	207	21	3.65	-	-	-	-	-	-	-	-
11/09/90 ¹	217	22	-	-	-	-	-	-	-	-	-

¹ Influent following the addition of lactate.

² Pore volume represents AMD entering column plus carboy storage.

³ Nitrogen reported as nitrate-N.

COLUMN STUDY --- EFFLUENT CHEMISTRY
COLUMN 3 - GREAT WESTERN MUSHROOM COMPOST

DATE	ELAP DAYS	PORE VOL	pH	EC	ORP (mv)	ACID. (mg/L)	ALK. (mg/L)	SULFATE (mg/L)	NITROGEN (mg/L) ²	TDS (mg/L)	ORGANIC CARBON (mg/L)
04/17/90	11	.5	7.45	15.49	-	-	-	-	-	-	-
04/24/90	18	.5	7.43	8.91	95	-	-	-	-	-	-
04/27/90	21	1	7.45	13.16	137	-	-	-	-	-	-
05/18/90	42	5	6.61	2.78	203	0	-	2350	0.90	1260	-
06/22/90	77	8	6.47	-	260	0	-	1410	-	2810	-
06/28/90	83	9	6.48	3.66	184	-	-	-	-	-	-
07/13/90	98	11	-	-	-	0	-	1250	-	2890	-
08/01/90	117	13	6.40	2.95	122	-	-	-	-	-	-
08/08/90	124	15	6.42	-	168	0	-	1710	-	2770	13
08/23/90	139	16	6.90	2.97	-	-	-	-	-	-	-
08/24/90	140	17	6.38	3.27	149	-	-	-	-	-	-
08/30/90	146	17	7.09	2.54	135	-	-	-	-	-	-
09/07/90	154	19	6.48	-	-	-	-	-	-	-	-
09/07/90	154	19	6.50	3.39	187	-	-	-	-	-	-
09/08/90	155	19	-	-	-	-	-	1500	<.05	2870	20
09/15/90	162	20	-	-	-	-	-	1450	<.05	2890	22
09/18/90	165	20	6.61	3.16	-	-	-	-	-	-	-
09/19/90	166	20	6.73	3.18	233	-	-	-	-	-	-
11/05/90 ¹	213	22	6.77	4.00	355	-	-	-	-	-	-
11/13/90 ¹	221	22	6.71	3.86	226	-	-	-	-	-	-
11/16/90 ¹	224	23	6.92	4.94	222	-	-	-	-	-	-
11/21/90 ¹	229	23	-	-	-	-	-	2200	4.7	6080	654
11/26/90 ¹	234	23	7.05	5.02	178	-	-	-	-	-	-

¹ Effluent following the addition of lactate.

² Nitrogen reported as nitrate-N through day 160. Reported as TKN following day 160.

COLUMN STUDY --- INFLUENT CHEMISTRY
COLUMN 4 - UNITED FOODS

DATE	ELAP DAYS	PORE VOL ²	pH	EC	ORP (mv)	ACID. (mg/L)	ALK. (mg/L)	SULFATE (mg/L)	NITRATE ³ (mg/L)	TDS (mg/L)	ORGANIC CARBON (mg/L)
04/10/90	4	.5	2.76	2.45	493	-	-	-	-	-	-
05/09/90	33	2	-	-	-	1060	0	1570	-	2580	-
05/14/90	38	2	-	-	-	-	-	-	-	-	-
06/11/90	66	3	-	-	-	-	-	-	-	-	-
06/18/90	73	6	-	-	-	-	-	-	-	-	-
07/02/90	87	10	-	-	-	1000	0	1650	-	2620	2
08/06/90	122	12	2.80	2.45	-	1020	-	1760	-	2770	2
08/13/90	129	16	-	-	-	-	-	-	-	-	-
08/28/90	144	17	-	-	-	980	-	1640	-	2670	-
09/07/90	154	17	2.64	-	-	-	-	-	-	-	-
09/14/90	161	17	-	-	-	1040	-	1730	-	2520	-
10/29/90 ¹	206	22	-	-	-	235	0	1750	-	8440	-
10/30/90 ¹	207	22	4.05	-	-	-	-	-	-	-	-
11/09/90 ¹	217	23	-	-	-	-	-	-	-	-	-

¹ Influent following the addition of lactate.

² Pore volume represents AMD entering column plus carboy storage.

³ Nitrogen reported as nitrate-N.

COLUMN STUDY --- EFFLUENT CHEMISTRY
COLUMN 4 - UNITED FOODS

DATE	ELAP DAYS	PORE VOL	pH	EC	ORP (mv)	ACID. (mg/L)	ALK. (mg/L)	SULFATE (mg/L)	NITROGEN ² (mg/L)	TDS (mg/L)	ORGANIC CARBON (mg/L)
04/17/90	11	.5	6.03	20.00	493	-	-	-	-	-	-
04/24/90	18	.5	6.67	-	94	-	-	-	-	-	-
04/27/90	21	1	6.86	-	137	-	-	-	-	-	-
05/07/90	31	2	6.56	-	220	-	-	-	-	-	-
05/11/90	35	2	5.85	-	283	-	-	-	-	-	-
05/18/90	42	3	6.34	3.04	298	0	420	1940	.14	5350	570
06/22/90	77	8	6.47	-	215	0	1740	1640	-	4430	-
06/28/90	83	9	7.20	5.05	150	-	-	-	-	-	-
07/12/90	97	10	-	-	493	0	1250	1800	-	4160	70
08/01/90	117	11	6.47	3.50	133	-	-	-	-	-	-
08/08/90	124	14	5.99	-	222	0	167	2260	-	3470	16
08/23/90	139	17	6.67	2.58	493	-	-	-	-	-	-
08/24/90	140	17	5.98	3.12	257	-	-	-	-	-	-
08/30/90	146	18	6.96	2.62	253	-	-	-	-	-	-
09/07/90	154	18	5.98	-	-	-	-	-	-	-	-
09/07/90	154	18	6.25	3.34	198	-	-	-	-	-	-
09/08/90	155	18	-	-	-	0	237	1980	<.05	3310	19
09/15/90	164	19	-	-	-	0	193	2040	<.05	3380	18
09/18/90	165	20	6.09	3.23	-	-	-	-	-	-	-
09/19/90	166	20	6.41	3.33	245	-	-	-	-	-	-
11/05/90 ¹	213	21	6.34	3.05	320	-	-	-	-	-	-
11/13/90 ¹	221	22	6.64	3.85	289	-	-	-	-	-	-
11/16/90 ¹	224	23	6.38	5.87	228	-	-	-	-	-	-
11/21/90 ¹	229	23	-	-	-	<1	2700	2840	4.3	8160	-
11/26/90 ¹	234	24	6.67	5.15	169	-	-	-	-	-	-

¹ Effluent following the addition of lactate.

² Nitrogen reported as nitrate-N through day 160. Reported as TKN following day 160.

COLUMN STUDY --- INFLUENT CHEMISTRY
COLUMN 5 - PEACO PEAT

DATE	ELAP DAYS	PORE VOL ²	pH	EC	ORP (mv)	ACID. (mg/L)	ALK. (mg/L)	SULFATE (mg/L)	NITRATE ³ (mg/L)	TDS (mg/L)	ORGANIC CARBON (mg/L)
04/08/90	2	.5	2.74	2.47	493	-	-	-	-	-	-
05/09/90	33	2	-	-	-	1040	0	1560	-	2510	-
05/14/90	38	2	-	-	-	-	-	-	-	-	-
06/11/90	66	4	-	-	-	-	-	-	-	-	-
07/03/90	88	7	-	-	-	1040	0	1640	-	2870	2
07/30/90	115	9	-	-	-	-	-	-	-	-	-
08/06/90	122	11	2.80	2.45	-	1020	0	1710	-	2910	2
08/13/90	131	13	-	-	-	-	-	-	-	-	-
08/21/90	137	14	-	-	-	989	-	1670	-	2600	-
08/31/90	147	16	-	-	-	-	-	-	-	-	-
09/07/90	154	17	2.65	-	-	-	-	-	-	-	-
10/29/90 ¹	206	18	-	-	-	578	0	1800	-	5350	-
10/30/90 ¹	207	18	3.64	-	-	-	-	-	-	-	-
11/08/90 ¹	216	19	-	-	-	-	-	-	-	-	-

¹ Influent following the addition of lactate.

² Pore volume represents AMD entering column plus carboy storage.

³ Nitrate represents nitrogen as nitrate-N.

COLUMN STUDY --- EFFLUENT CHEMISTRY
COLUMN 5 - PEACO PEAT

DATE	ELAP DAYS	PORE VOL	pH	EC	ORP (mv)	ACID. (mg/L)	ALK. (mg/L)	SULFATE (mg/L)	NITROGEN (mg/L) ²	TDS (mg/L)	ORGANIC CARBON (mg/L)
04/17/90	11	0	6.19	2.86	493	-	-	-	-	-	-
04/24/90	18	.5	6.46	1.42	532	-	-	-	-	-	-
04/27/90	21	.5	6.84	1.85	690	-	-	-	-	-	-
05/07/90	31	2	7.92	2.54	415	-	-	-	-	-	-
05/11/90	35	2	7.04	2.52	328	-	-	-	-	-	-
05/17/90	41	3	7.22	1.97	518	0	29	1500	.43	2350	12
06/22/90	77	6	6.86	0.00	369	0	108	1630	-	2570	-
06/28/90	83	7	6.83	3.03	287	-	-	-	-	-	-
07/13/90	98	8	-	-	493	0	53	1710	-	2670	15
08/01/90	117	10	6.48	2.48	353	-	-	-	-	-	-
08/08/90	124	11	5.70	2.03	370	296	0	1630	-	2390	3
08/23/90	139	16	6.11	2.03	493	-	-	-	-	-	-
08/24/90	140	16	4.87	2.38	344	-	-	-	-	-	-
08/30/90	146	18	3.48	1.98	340	-	-	-	-	-	-
09/07/90	154	19	2.80	-	-	-	-	-	-	-	-
09/07/90	154	19	3.43	2.71	762	-	-	-	-	-	-
09/08/90	155	19	-	-	-	698	0	1650	<.05	2360	7
09/15/90	162	20	-	-	-	850	0	1700	<.05	2390	6
09/18/90	165	20	-	2.35	-	-	-	-	-	-	-
09/19/90	166	20	3.35	2.35	877	-	-	-	-	-	-
11/05/90 ¹	213	21	3.39	2.21	879	-	-	-	-	-	-
11/13/90 ¹	221	22	3.24	2.89	887	-	-	-	-	-	-
11/16/90 ¹	224	22	3.64	3.30	782	-	-	-	-	-	-
11/21/90 ¹	229	22	-	-	-	1350	<1	1870	2.4	4900	900
11/26/90 ¹	228	23	3.99	3.09	692	-	-	-	-	-	-

¹ Effluent following the addition of lactate.

² Nitrogen reported as nitrate-N through day 160. Reported as TKN following day 160.

COLUMN STUDY --- INFLUENT CHEMISTRY
COLUMN 6 - FARMERS PEAT

DATE	ELAP TIME	PORE VOL ²	pH	EC (mv)	ORP	ACID. (mg/L)	ALK. (mg/L)	SULFATE (mg/L)	NITRATE (mg/L) ³	TDS (mg/L)	ORGANIC CARBON (mg/L)
05/09/90	33	2	-	-	493	1020	0	1550	-	2440	-
06/11/90	66	4	-	-	493	-	-	-	-	-	-
06/25/90	80	7	-	-	493	978	0	1540	-	2850	-
07/30/90	115	9	-	-	-	-	-	-	-	-	-
08/13/90	129	12	-	-	493	1030	0	1780	-	2530	2
08/29/90	145	15	-	-	-	1030	-	1710	-	2690	-
09/07/90	154	15	2.48	-	-	-	-	-	-	-	-
10/29/90 ¹	206	17	-	-	-	641	0	1790	-	5260	-
10/30/90 ¹	207	17	3.58	-	-	-	-	-	-	-	-
11/08/90 ¹	216	18	-	-	-	-	-	-	-	-	-

¹ Influent following the addition of lactate.

² Pore volume represents AMD entering column plus carboy storage.

³ Nitrate represents nitrogen as nitrate-N.

COLUMN STUDY --- EFFLUENT CHEMISTRY
COLUMN 6 - FARMERS PEAT

DATE	ELAP TIME	PORE VOL	pH	EC	ORP (mv)	ACID. (mg/L)	ALK. (mg/L)	SULFATE (mg/L)	NITROGEN ² (mg/L)	TDS (mg/L)	ORGANIC CARBON (mg/L)
04/17/90	11	.5	3.72	2.90	493	-	-	-	-	-	-
04/24/90	18	1	3.94	1.49	871	-	-	-	-	-	-
04/27/90	21	1	4.27	1.93	840	-	-	-	-	-	-
05/07/90	31	2	5.33	3.34	709	-	-	-	-	-	-
05/11/90	35	2	5.70	2.34	565	-	-	-	-	-	-
05/17/90	41	3	5.35	2.03	896	158	0	1490	1.38	2350	3
06/22/90	77	6	4.47	0.00	950	8560	0	1420	-	2050	-
06/28/90	83	7	3.17	3.21	927	-	-	-	-	-	-
07/03/90	88	8	-	-	493	356	0	1518	-	2300	11
08/01/90	117	9	2.76	2.58	999	-	-	-	-	-	-
08/08/90	124	11	2.78	-	930	669	0	1650	-	2580	10
08/23/90	139	13	3.55	1.92	493	-	-	-	-	-	-
08/24/90	140	14	2.77	2.20	757	-	-	-	-	-	-
08/30/90	146	15	3.02	1.86	925	-	-	-	-	-	-
09/07/90	154	16	2.84	-	-	-	-	-	-	-	-
09/07/90	154	16	3.08	2.76	952	-	-	-	-	-	-
09/08/90	155	16	-	-	-	801	0	1590	<.05	2250	9
09/15/90	162	17	-	-	-	830	0	1640	<.05	2350	9
09/18/90	165	17	2.21	2.30	-	-	-	-	-	-	-
09/19/90	166	17	3.16	2.45	982	-	-	-	-	-	-
11/05/90 ¹	213	18	3.63	2.91	840	-	-	-	-	-	-
11/13/90 ¹	221	18	3.61	2.91	755	-	-	-	-	-	-
11/16/90 ¹	224	18	3.72	3.55	736	-	-	-	-	-	-
11/21/90 ¹	229	19	-	-	-	972	<1	1670	2.2	4390	1000
11/26/90 ¹	234	19	3.89	2.56	695	-	-	-	-	-	-

¹ Effluent following the addition of lactate.

² Nitrogen reported as nitrate-N through day 160. Reported as TKN following day 160.

APPENDIX B

MUSHROOM COMPOST AVAILABLE

PHYSICAL AND CHEMICAL CHARACTERISTICS

COLUMNS STUDY SUBSTRATE MATERIALS

1) GW MUSHROOM COMPOST

Supplier: Great Western Distributors/ O'Neil and Sons
P.O. Box 4128
Tumwater, Washington 98501
(206) 754-3722
FAX 754-3301
Contact: Rob

Producer: Ostrums Mushroom Farm
(206) 491-1410
Contact: Keith Highum

Cost: \$ 4 - 5.00/yd³ FOB

Shipping: Approximately \$25.00/yd³ from the Seattle, WA. area to Great Falls, MT.

SUBSTRATE COMPONENTS

	<u>% (wt)</u>	<u>% moisture</u>
1. small grain straw	57	10
2. cotton seed hulls	10	10
3. dried poultry waste (DPW)	11	25 or less
4. hardwood bark	3	-
5. brewers grain (spent malting barley)	10	70
6. gypsum	4	-
7. cotton seed meal	5	6 - 7

* Spent compost moisture content = 15.3%

* Spent compost nitrogen content = 2.1%

* Chemical analysis available

2) UNITED FOODS MUSHROOM COMPOST

Supplier: United Foods, Inc.
400 South Park Ave.
Fillmore, Utah 84631
(801) 743-6817
TELECOPIER 801-743-5812
Contact: Eric Noffsinger, Loyal Adams

Producer: Fillmore Mushroom Farm
Fillmore (area), Utah

Cost: \$1.50 / yd³ (\$75.00 /load, trucks loaded at plant with ~ 25 ton or ~ 48 yd³)

Shipping: Approximately \$25.00/yd³ from the Fillmore, UT. area to Great Falls, MT.

Source 1. Molarway Freight Lines, Inc.

Billings, MT.

(406) 256-7722

Contact: Conn Molar

-- Salt LC to G Falls -- \$2.03 / 100wt. (\$850.00 / 42,000 lb truck)

(42,000 lb @ 1300 lb/yd³ = 32.3 yd; \$850 / 32.3 yd³
= \$26.31 / yd³)

SUBSTRATE COMPONENTS

Components include: wheat straw, peat moss, DPW (dried poultry waste), cottonseed meal, canola meal, urea, gypsum, lime.

Exact component percentages are considered proprietary information by the producer.

* Chemical analysis is available from the distributor.

3) EKO-COMPOST

Supplier: EKO Systems, Inc.
3700 Compost Rd.
P.O. Box 9168
Missoula, MT. 59807
(800) 232-5356
FAX (406) 721-7526
Contact: John Leinan

Cost: \$13.00/ton FOB (@ approximately 1300 lb/yd³ = \$8.50/yd³)

Shipping: Use 1990 shipping costs (Molarway, Inc.)

SUBSTRATE COMPONENTS

	<u>% (wt)</u>	<u>% moisture</u>
Wood waste	80	20
Sewage sludge	20	6

- * Typical compost moisture content when shipped = 57.2%
- * Typical compost total nitrogen content = 1.5%
- * Chemical analysis is available

4) GROCO

Supplier: Great Western Distributors / O'Neil and Sons
P.O. Box 4128
Tumwater, WA. 98501
(206) 754-3722
FAX (206) 754-3301
Contact: Rob

Producer: Produced from sewage sludge from the Seattle, WA. area.

Cost: \$8.00/yd³ FOB (availability uncertain)

Shipping: Approximately \$25.00/yd³ from Tumwater, WA. to Great Falls, MT.

SUBSTRATE COMPONENTS: Consists of wood waste and sewage sludge

- * Chemical analysis is available

5) FARMERS PLANT PEAT

Supplier: Farmers Plant
Hamilton, MT. area
(406) 363-3505
Contact: Coby Smith

Producer: Peat bogs in the Wisdom, MT. area

Cost: \$8.50/yd³

Shipping: Approximately \$10.00/yd³ from the Wisdom, MT. area to Great Falls

Source 1. Tran-systems
Great Falls, Mt.
~ \$8.50 /yd³

SUBSTRATE COMPONENTS: Native peat

* Chemical analysis not currently available from Portland office

6) PEACO PEAT

Supplier: Peaco Peat Moss
Polson, MT. area
(406) 849-5729
Contact: Terry Tompkins

Producer: 70 natural bog in the Polson, MT. area containing approximately 1.5 million yd³ total

Cost: \$20.00 /yd³ FOB (in bulk)

Shipping: Approximately \$10.00/yd³ from the Polson area to Great Falls, MT.

Source 1. Peaco Peat Moss (would prefer a private shipping line)
Polson, MT.
\$2.50 /yd³ /loaded mile via tractor-trailer
(\$2.50 x 250 miles = \$625
\$625 / 30 yd³ = \$20.80 / yd³)

SUBSTRATE COMPONENTS: Consists of native peat; brown, hypnum type, non-acidic

* Chemical analysis available from distributor

7) DRIED POULTRY WASTE (DPW)

Supplier: 1. EKO-systems, Inc.
Missoula, MT.
Cost: \$120 / ton
Shipping: ?
Producer: Morning Fresh Farms, Platteville, CO.
* Chemical analysis included in Appendix X**

Potential Suppliers:

1. Morning Fresh Farms
15121 WCR 32
Platteville, CO.
2. Stutzman Farm
Oregon (referred to by Keith Highum of Ostrums Farm)
Cost: \$35/ton FOB
Shipping: Approximately \$25.00/ton (based on rates from the
Seattle, WA. area)
3. Cherry Lanes
Three Fork, MT.

NITROGEN CONTENT IN MANURES¹

	<u>% NITROGEN</u>	
	<u>Available NH₄</u>	<u>Total N (NH₄ + ORG)</u>
Beef cattle	0.2 - 0.4	.55 - 1.05
Dairy cattle	0.2 - .25	.45
Poultry	1.3 - 1.8	1.65 - 2.8
Swine	.25	.40

* low side of range = w/o bedding; high side of range = w/ bedding

¹ Follett, R.H., L.S. Murphy, and R.L. Donoghue. 1981. Fertilizers and soil amendments. Prentice-Hall, Inc., Englewood Cliffs, N.J. pg. 478.

BLENDS OF WETLAND SUBSTRATE MATERIALS

COST - BENEFIT ANALYSIS

POTENTIAL BLENDS	COMPONENTS ¹											SHIPPING ³	TOT. COST(Yd ³)	
	#1-EK%	#2-GR%	#3-GW%	#4-UF%	#5-PP%	#6-FP%	#7-DP%	#8-CM% ²	#9-WS% ²	#10-SB%	#11-CA%			COST(Yd ³)
1)	33					33	33					\$17.65	\$13.20	\$30.85
2)	33					33		33				\$ 7.75	\$ 8.25	\$16.00
3)	50						25	25				\$14.25	\$11.25	\$25.50
4)	50							50				\$ 6.75	\$ 7.50	\$14.25
5)	75							25				\$ 7.67	\$ 6.25	\$13.92
6)	50			50								\$ 5.00	\$15.00	\$20.00
7)	75			25								\$ 6.74	\$10.00	\$16.74
8)	75						25					\$15.12	\$10.00	\$25.12
9)						50		50				\$ 7.50	\$10.00	\$17.50
10)						75		25				\$ 8.75	\$10.00	\$18.75
11)						85	15					\$13.75	\$12.25	\$26.00
12)							15		60	25		\$10.75	\$12.25	\$23.00
13)								25	60	15		\$ 5.75	\$10.00	\$15.75
14)							15		60		25	\$10.75	\$12.25	\$23.00
15)								25	60		15	\$ 5.75	\$10.00	\$15.75
SELECTED BLENDS														
1)	35							30	35			\$ 7.80	\$10.00	\$17.80
2)						35		30	35			\$ 6.75	\$10.00	\$16.75
3)								30	70			\$ 5.00	\$10.00	\$15.00
4)						40		60				\$ 7.00	\$10.00	\$17.00
5)						40	15	45				\$11.50	\$12.25	\$23.75
6)						30		30	30	10		\$14.50	\$10.00	\$24.50

Substrate Components

#1-EK = EKO-Compost consists of 80% wood waste + 20% sewage sludge @ \$13.00/yd³ FOB + \$10.00/yd³ shipping from Missoula, MT.
 #2-GR = Groco consists of composted wood waste + sewage sludge @ \$8.00/yd³ FOB + \$25.00/yd³ shipping from the Seattle, WA. area.
 #3-GW = Great Western compost consists of spent mushroom compost @ \$5.00/yd³ FOB + \$25.00/yd³ shipping from the Seattle, WA. area.
 #4-UF = United Foods compost consists of spent mushroom compost @ \$1.50/yd³ FOB + \$25.00/yd³ shipping from the Salt Lake City, UT. area.
 #5-PP = Peaco peat moss consists of native peat @ \$20.00/yd³ FOB + \$10.00/yd³ shipping from the Polson, MT. area.
 #6-FP = Farmers Aid Plant peat moss consists of chicken manure @ \$35.00/yd³ FOB + \$10.00/yd³ shipping from the Hamilton, MT. area.
 #7-DP = DPW (dried poultry waste) consists of chicken manure @ \$35.00/yd³ FOB + \$25.00/yd³ shipping from Oregon.
 #8-CM = Cattle manure @ \$5.00/yd³ FOB + \$10.00/yd³ shipping from local area feedlots.
 #9-WS = Wheat straw @ \$5.00/yd³ (ton) FOB + \$10.00/yd³ shipping from local area farmers.
 #10-SB= Sugar beet waste @ \$85.00/yd³ (ton) FOB + \$10.00/yd³ shipping from eastern Montana sugar beet plants.
 #11-CA= Canola meal waste @ \$120.00/yd³ (ton) FOB + \$14.00/yd³ shipping from the Lethbridge, Alberta, Canada area.

- Substrate component prices and availability are variable.
- FOB costs are estimated and may vary with agricultural conditions.
- Approximate shipping costs from distributor to the Great Falls, MT. area. Additional handling costs may be incurred.



EKO SYSTEMS

P.O. Box 9168

Missoula, MT 59807

Soil and Plant Laboratory, Inc.

SOIL FERTILITY AND AGRICULTURAL SUITABILITY (AOH)

19 December 1989

Samples received: 15 Dec. 1989

Sam ple #	Half Sat. %	Parts Per Million Dry Soil						pH	Saturation Extract Values							SAR	QUAL LIME
		NO ₃ -N NH ₄ -N PO ₄ -P K				Ca	Mg		ECe	Ca Me/l	Mg Me/l	Na Me/l	K Me/l	B PPM			
1	106	500	472	275	1215	4439	645	6.5	3.3	6.9	4.3	7.3	4.9	0.50	3.1	LOW	
2	134	1347	532	420	1535	5792	832	5.9	4.2	12.8	6.5	6.4	6.1	0.50	2.1	LOW	
3	128	1847	28	414	1232	6108	941	5.1	6.3	38.0	14.5	7.3	6.5	0.64	1.4	LOW	

Half Saturation % = approx. field moisture capacity. Salinity = ECe (mmhos/cm at 25 degrees C.).
SAR = Sodium Adsorption Ratio

- (1) Eko Compost phase I
- (2) Eko Compost phase II "89"
- (3) Eko Compost phase IV "90"



EKO SYSTEMS
P.O. Box 9168
Missoula, MT 59807

Soil and Plant Laboratory, Inc.

ORGANIC AMENDMENT ANALYSIS (A07)

20 December 1989
Samples received: 15 Dec. 1989

Values based upon dry weight

Values based upon dry weight														
Sam ple #	pH	ECe	H2O % as Received	Bulk Density lbs/yd3	Org %	percent passing					Total		Half Saturation %	
						19.51 mm	6.35 mm	4.75 mm	2.38 mm	1.00 mm	.500 mm	Nitrogen %		H+ Soluble Iron %
1	6.5	3.3	57.2	404	80.4	95.2	82.4	73.3	56.7	28.3	13.9	1.57	0.122	106
2	5.9	4.2	59.6	478	74.7	97.8	94.3	89.9	74.0	41.0	19.8	1.51	0.128	134
3	5.1	6.3	59.4	487	71.9	99.1	95.3	90.7	73.8	42.1	19.6	1.33	0.118	128

Half Saturation % = approx. field moisture capacity. ECe (mmhos/cm @ 25 deg. C.) by saturation extract method.



University of Montana

Missoula, Montana 59812

November 30, 1984

RESULTS OF ANALYSES ICAP JOB NO. 129

ppm of	Canadian Sphagnum Peat		Eko-Compost		L.O.D.
	Replicate #1	Replicate #2	Replicate #1	Replicate #2	
Aluminum	29.2	29.2	7.7	7.8	.3
Boron	.20	.04	1.48	1.43	.15
Calcium	5504	5448	4672	4550	.2
Cadmium	.12	.12	.39	.37	.04
Copper	3.12	2.24	9.44	9.25	.04
Iron	266	264	79.2	78.6	.05
Magnesium	1768	1744	869	849	.4
Manganese	46.2	45.8	89.1	83.0	.02
Mercury	5.3	4.7	3.6	3.6	.1
Potassium	265	81	632	634	4
Molybdenum	0	0	.05	.09	.07
Phosphorus	30.0	33.2	126	124	.6
Sodium	95.2	67.2	583	569	.3
Silicon	57.2	52.8	42.5	42.7	.2
Zinc	10.6	7.84	59.6	58.1	.02
Titanium	1.20	1.12	.65	.87	.02
Total Nitrogen	7900	7930	12810	11920	70

¹ Limit of detection

Don A. Essig
Don A. Essig
Chemical Analyst

CAMAS ANALYTICAL LABORATORY, INC.
P.O. BOX 3694, MISSOULA, MT 59806
N. Stark, Ph.D.; D. Essig, M.S.; S. Baker, B.S.; & G. Butler
PH. 406-726-3744

JOB NO. 30

October 1, 1987

EKO

	ppm
Al	2.4
B	3.1
Ca	8384
Cd	0.96
Co	0.08
Cu	48.1
Fe	49.4
Mg	1470
Mn	75.7
Hg	0
Mo	0.2
P	532
K	1710
Si	70.7
Zn	158
N, total	9582
Ti	0.25
Na	811

pH 6.35

Laucks

Testing Laboratories, Inc.



Certificate

940 South Harney St. Seattle, Washington 98108 (206)767-5060

Chemistry, Microbiology, and Technical Services

CLIENT: Groco, Inc.
15 South Spokane Street
Seattle, WA 98134
ATTN: Curley

LABORATORY NO. 5983

DATE: October 5, 1987

REPORT ON: GROCO

SAMPLE
IDENTIFICATION: Submitted 09/17/87

TESTS PERFORMED AND RESULTS:

	<u>1</u>	<u>2</u>	<u>3</u>	<u>4</u>	<u>5</u>	<u>5 Dup</u>
Total Solids, %	31.6	34.7	37.3	40.0	33.4	33.3
Salmonella	Negative	Negative	Negative	Negative	Negative	
Total Coliform MPN/gm	<3	<3	<3	<3	<3	
Fecal Coliform MPN/gm	<3	<3	<3	<3	<3	
Fecal Strep MPN/gm	<3	<3	<3	<3	<3	

parts per million (mg/kg), dry basis

Total Cadmium	12.	10.	10.	12.	10.
---------------	-----	-----	-----	-----	-----

Key

< indicates "less than"

Respectfully submitted,

Laucks Testing Laboratories, Inc.

Joseph M. Clark
Joseph M. Clark

JMC:emt



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Soil and Plant Laboratory, Inc.

SOIL FERTILITY AND
MICRONUTRIENT ANALYSIS
(A01 OR A17)

RO CO INC.
.O. Box 80502
Seattle, WA 98108

December 1986
Sample received: 3 December 1986

Sample #	Half Sat. %	pH	ECe	Parts Per Million Dry Soil										Sat. Extract		SAMPLE DESCRIPTION
				NO ₃ -N	NH ₄ -N	PO ₄ -P	K	Ca	Mg	Cu	Zn	Mn	Fe	B	ppm	

Gro-Co

1	148	0.0		698	2668	272	399	2857	492	60	170	50	266	0.42			
---	-----	-----	--	-----	------	-----	-----	------	-----	----	-----	----	-----	------	--	--	--

Half Saturation % = approx. field moisture capacity. ECe (mmhos/cm @ 25 deg. C.) by sat. extract method. Major elements by sodium acetate and sodium bicarbonate extraction. Micronutrients by DTPA extraction except boron by saturation extraction.
*** means below the detection limit for the element.

ORGANIC AMENDMENT ANALYSIS (A07)

Values based upon dry weight

Sam ple #	pH	ECe	H2O % as Received	Values based upon dry weight										
				Bulk Density lbs/yd3	Org %	percent passing					Total H+ Soluble		Half Saturation %	
						19.51 mm	6.35 mm	4.75 mm	2.38 mm	1.00 mm	.500 mm	Nitrogen %		Iron %
1	6.1	4.5	69.9	357	86.1	90.9	82.0	73.2	28.0	4.9	1.5	0.80	0.563	148

Half Saturation % = approx. field moisture capacity. ECe (mmhos/cm @ 25 deg. C.) by saturation extract method.

P.O. Box 11744, Santa Ana, California 92711-1744/(714) 558-8333
P.O. Box 153, Santa Clara, California 95052-0153/(408) 727-0330
P.O. Box 1648, Bellevue, Washington 98009-1648/(206) 746-8685



**SOIL FERTILITY AND
MICRONUTRIENT ANALYSIS
(A01 OR A17)**

P.O. Box 6566, Orange, California 92613-8566 (714) 282-8777/FAX (714) 282-8575
P.O. Box 153, Santa Clara, California 95052-0153/(408) 727-0330/FAX (408) 727-5125
P.O. Box 1648, Bellevue, Washington 98009-1648/(206) 746-6665

Half Saturation % = approx. field moisture capacity. Ece (mmhos/cm @ 25 deg. C.) by sat. extract method. Major elements by sodi acetate and sodium bicarbonate extraction. Micronutrients by DTPA extraction except boron by saturation extraction.

Values based upon dry weight

Half Saturation % = approx. field moisture capacity. ECE (mmhos/cm @ 25 deg. C.) by saturation extract method.

LABORATORY ANALYSIS REPORT

REPORT TO: Mike

LAB NO: 8005

DATE RCVD: 7-18-88

BILL TO: Morning Fresh Farms, Inc.
15121 WCR 32
Platteville, CO 80651

REPORTED: 7-28-88

P.O. #:

=====

ANALYSIS REQUESTED:

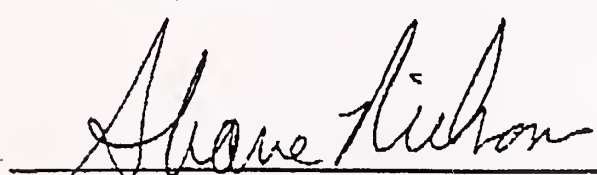
1 Dried Poultry Waste Sample for Analysis

=====

ANALYSIS REPORT:

Dried Poultry
Waste 7-18-88

pH (units)	6.94
Total Nitrogen (% as N)	4.93
Ammonia Nitrogen (%)	0.698
Nitrate Nitrogen (%)	0.019
Organic Nitrogen (%)	4.21
Phosphorus (% as P2O5)	3.31
Potassium (% as K2O)	2.83
Iron (ppm)	1,130.
Copper (ppm)	59.
Manganese (ppm)	320.
Zinc (ppm)	510.
Sulfur (% as SO4-S)	0.77
Calcium (%)	8.70
Magnesium (%)	0.51
Sodium (%)	0.67
Molybdenum (ppm)	11.6


Analysis Supervised By


Data Approved for Release By

APPENDIX C
COLUMN PORE WATER CHEMISTRY

COLUMNS STUDY
PORT SOLUTION CHEMISTRY
9/05/90

COL#	DEPTH ¹	AL ²	MOLAR Al	Fe	MOLAR Fe	Mn	MOLAR Mn	Zn	MOLAR Zn
1	1	97.7	0.003621	77.3	0.001384	0.31	0.000006	0.01	0.000000
1	2	53.1	0.001968	21.5	0.000385	0.19	0.000003	0.02	0.000000
1	3	98.9	0.003666	74.5	0.001334	0.77	0.000014	2.10	0.000032
1	4	76.1	0.002821	178.0	0.003187	0.24	0.000004	3.05	0.000047
1	5	47.5	0.001761	220.0	0.003939	0.06	0.000001	1.79	0.000027
1	6	64.4	0.002387	98.6	0.001765	0.58	0.000011	2.07	0.000032
2	1	55.7	0.002064	166.0	0.002972	1.30	0.000024	0.01	0.000000
2	2	4.8	0.000178	150.0	0.002686	5.25	0.000096	0.01	0.000000
2	3	122.0	0.004522	107.0	0.001916	0.22	0.000004	0.02	0.000000
2	4	121.0	0.004485	94.5	0.001692	0.19	0.000003	2.33	0.000036
2	5	94.7	0.003510	77.9	0.001395	0.15	0.000003	2.72	0.000042
2	6	94.5	0.003503	76.7	0.001373	0.13	0.000002	2.76	0.000042
3	1	0.5	0.000019	0.6	0.000011	1.36	0.000025	0.11	0.000002
3	2	0.1	0.000004	1.2	0.000021	1.21	0.000022	0.03	0.000000
3	3	0.2	0.000007	47.4	0.000849	1.32	0.000024	0.01	0.000000
3	4	116.0	0.004299	85.0	0.001522	0.33	0.000006	1.90	0.000029
3	5	106.0	0.003929	81.9	0.001466	0.16	0.000003	3.38	0.000052
3	6	91.2	0.003380	84.1	0.001506	0.07	0.000001	2.81	0.000043
4	1	0.2	0.000007	3.9	0.000070	2.41	0.000044	1.00	0.000015
4	2	0.1	0.000004	61.8	0.001107	1.27	0.000023	0.03	0.000000
4	3	83.7	0.003102	88.0	0.001576	0.37	0.000007	0.01	0.000000
4	4	98.2	0.003640	63.2	0.001132	0.30	0.000005	1.01	0.000015
4	5	97.8	0.003625	51.1	0.000915	0.27	0.000005	3.22	0.000049
4	6	86.7	0.003213	78.7	0.001409	0.12	0.000002	2.50	0.000038
5	1	78.3	0.002902	114.0	0.002041	0.07	0.000001	0.76	0.000012
5	2	114.0	0.004225	60.7	0.001087	0.25	0.000005	2.15	0.000033
5	3	120.0	0.004448	54.4	0.000974	0.17	0.000003	2.37	0.000036
5	4	84.9	0.003147	79.6	0.001425	0.17	0.000003	2.58	0.000039
5	5	78.1	0.002895	160.0	0.002865	0.02	0.000000	2.24	0.000034
5	6	76.9	0.002850	83.1	0.001488	0.26	0.000005	2.25	0.000034
6	1	100.0	0.003706	66.5	0.001191	0.33	0.000006	2.84	0.000043
6	2	125.0	0.004633	52.4	0.000938	0.44	0.000008	2.58	0.000039
6	3	119.0	0.004411	66.9	0.001198	0.48	0.000009	2.87	0.000044
6	5	94.9	0.003517	43.7	0.000782	0.37	0.000007	2.40	0.000037
6	6	90.8	0.003365	46.1	0.000825	0.29	0.000005	2.40	0.000037

- Depth increments represent the distance below approximate standing water level. Depth 1 = 10cm, Depth 2 = 36cm, Depth 3 = 50cm, Depth 4 = 64cm, Depth 5 = 72cm, Depth 6 = 80cm.
- Solution concentrations presented in mg/L.

COLUMNS STUDY
PORT SOLUTION CHEMISTRY
9/18/90

COL.#	DEPTH ¹	REDOX (mv)	ORP	pH	SULFIDE	Al ²	MOLAR Al	Fe	MOLAR Fe	Mn	MOLAR Mn	Zn	MOLAR Zn
1	1	77	570	4.04	5.800	105.0	0.003892	84.7	0.001517	0.20	0.000004	0.01	0.000000
1	2	148	641	3.54	3.500	134.0	0.004967	56.8	0.001017	0.30	0.000005	0.15	0.000002
1	3	272	765	5.68	1.300	93.1	0.003451	52.8	0.000945	0.44	0.000008	2.56	0.000039
1	4	325	818	4.66	0.250	94.2	0.003491	46.9	0.000840	0.25	0.000005	2.72	0.000042
1	5	478	971	2.67	0.000	94.3	0.003495	64.1	0.001148	0.17	0.000003	2.54	0.000039
1	6	533	1026	2.79	0.000	88.1	0.003265	67.8	0.001214	0.21	0.000004	2.56	0.000039
2	1	23	516	4.12	8.300	67.8	0.002513	128.0	0.002292	1.10	0.000020	0.01	0.000000
2	2	31	524	5.77	0.190	2.4	0.000089	151.0	0.002704	5.51	0.000100	0.16	0.000002
2	3	135	628	3.56	3.000	125.0	0.004633	103.0	0.001844	0.36	0.000007	0.04	0.000001
2	4	230	723	2.98	1.400	120.0	0.004448	96.5	0.001728	0.30	0.000005	2.17	0.000033
2	5	414	907	2.70	0.000	94.3	0.003495	85.2	0.001526	0.09	0.000002	2.57	0.000039
2	6	487	880	2.76	0.000	90.3	0.003347	68.5	0.001226	0.13	0.000002	2.50	0.000038
3	1	-175	318	6.97	31.100	0.5	0.000019	0.8	0.000014	1.32	0.000024	0.04	0.000001
3	2	-202	291	7.41	18.600	5.3	0.000196	4.2	0.000075	1.14	0.000021	0.33	0.000005
3	3	30	523	6.29	0.290	2.1	0.000078	52.8	0.000945	0.31	0.000006	0.04	0.000001
3	4	250	743	2.54	0.080	134.0	0.004967	83.6	0.001497	0.24	0.000004	2.04	0.000031
3	5	420	913	1.89	0.000	109.0	0.004040	80.7	0.001445	0.22	0.000004	3.23	0.000049
3	6	486	979	1.70	0.000	99.8	0.003699	83.8	0.001500	0.08	0.000001	2.75	0.000042
4	1	-31	462	5.46	1.670	0.2	0.000007	7.9	0.000141	1.19	0.000022	0.05	0.000001
4	2	-27	466	4.26	0.750	2.0	0.000074	78.8	0.001411	0.82	0.000015	0.01	0.000000
4	3	92	585	3.76	4.640	98.4	0.003647	77.1	0.001380	0.29	0.000005	0.04	0.000001
4	4	214	707	2.87	0.290	124.0	0.004596	56.8	0.001017	0.36	0.000007	2.36	0.000036
4	5	426	919	2.62	0.130	108.0	0.004003	54.7	0.000979	0.36	0.000007	5.07	0.000078
4	6	526	1019	1.76	0.002	95.9	0.003554	89.1	0.001595	0.12	0.000002	2.70	0.000041
5	1	133	526	5.09	0.290	119.0	0.004411	85.8	0.001536	0.35	0.000006	1.20	0.000018
5	2	145	638	4.76	0.080	111.0	0.004114	79.7	0.001427	0.73	0.000013	1.64	0.000025
5	3	130	623	5.34	0.600	114.0	0.004225	63.1	0.001130	0.31	0.000006	2.36	0.000036
5	4	164	557	4.95	0.220	93.2	0.003454	79.5	0.001423	0.33	0.000006	2.65	0.000041
5	5	437	930	2.69	0.000	82.6	0.003062	67.1	0.001201	0.27	0.000005	2.28	0.000035
5	6	414	907	2.73	0.000	87.0	0.003225	74.4	0.001332	0.30	0.000005	2.46	0.000038
6	1	188	681	5.29	0.110	110.0	0.004077	64.7	0.001158	0.68	0.000012	2.75	0.000042
6	2	206	699	4.93	0.100	99.2	0.003677	50.9	0.000911	0.51	0.000009	2.06	0.000032
6	3	215	708	4.89	0.130	110.0	0.004077	71.5	0.001280	0.55	0.000010	2.77	0.000042
6	4	222	715	4.69	0.310	101.0	0.003744	51.1	0.000915	0.48	0.000009	2.15	0.000033
6	5	258	751	4.67	0.480	96.9	0.003592	48.9	0.000876	0.44	0.000008	2.19	0.000034
6	6	386	879	4.41	0.070	87.5	0.003243	53.9	0.000965	0.41	0.000007	2.29	0.000035

- 1 Depth increments represent the distance below approximate standing water level. Depth 1 = 10cm, Depth 2 = 36cm, Depth 3 = 50cm,
Depth 4 = 64cm, Depth 5 = 72cm, Depth 6 = 80cm.
2 Solution concentrations presented in mg/L.

APPENDIX D
COLUMN SUBSTRATE METALS
FRACTIONATION RESULTS

Table D.1. Substrate Metal Removal By Sorbed And Solid Fractions.

ALUMINUM	Fraction	Eko Compost				Groco			
		Before	After	Removed	% Total	Before	After	Removed	% Total
IRON	Soluble	7.51	58.05	50.54	0.52	23.04	63.63	40.59	0.77
	Exchangable	82.59	523.97	441.38	4.57	122.86	238.9	116.04	2.20
	Organ. Bound	1225.75	9203.11	7977.36	82.60	3902.11	3408.58	-493.53	
	Carbonate	364.16	1390.59	1026.43	10.63	547.75	5560.94	5013.19	95.22
	Oxide	172.69	334.72	162.03	1.68	235.48	330.54	95.06	1.81
	Residual	1291.44	1183.42	-108.02		747.4	698.15	-49.25	
	Total	3144.14	12693.87	9549.72	100	5578.64	10300.74	4722.1	100
	Total Adj.			9657.74				5264.88	
	Fraction								
	Soluble	7.51	38.06	30.55	39.63	21.76	53.07	31.31	4.82
	Exchangable	1892.12	181.69	-1710.43	60.37	92.15	165.96	73.81	11.35
	Organ. Bound	135.15	1795.64	1660.49		3931.55	2737.07	-1194.48	
	Carbonate	1464.14	843.65	-620.49		1203.01	1747.99	544.98	83.83
	Oxide	2147.4	1598.84	-548.56		1197.89	1067.38	-130.51	
	Residual	1006.13	957.64	-48.49		773	721.3	-51.7	
	Total	6652.45	5415.52	-1236.93	100	7219.36	6492.77	-726.59	100
	Total Adj.			77.09				650.11	
	Fraction								
	Soluble	7.51	38.06	30.55	39.63	21.76	53.07	31.31	4.82
	Exchangable	1892.12	181.69	-1710.43	60.37	92.15	165.96	73.81	11.35

NOTE:Percent Removal determined from comparison of substrate metal fraction concentrations (mg/Kg) before and after exposure to AMD.
Adjusted Total is sum of only positive values.

MANGANESE

Fraction	Eko Compost				Groco		
	Before	After	Removed	% Total	Before	After	Removed
Soluble	11.26	2.71	-8.55		5.12	9.78	4.66
Exchangable	30.03	15.02	-15.01		30.72	19.47	-11.25
Organ. Bound	337.88	3.82	-334.06		184.29	7.63	-176.66
Carbonate	150.17	1.88	-148.29		174.05	9.09	-164.96
Oxide	22.52	6.47	-16.05		71.67	3.89	-67.78
Residual	24.4	16.41	-7.99		10.24	8.6	-1.64
Total	576.26	46.31	-529.95		476.09	58.46	-417.63
Total Adj.			0				4.66
							100

ZINC

Fraction	Eko Compost				Groco		
	Before	After	Removed	% Total	Before	After	Removed
Soluble	11.26	72.44	61.18	9.37	3.84	131.85	128.01
Exchangable	45.05	408.23	363.18	55.61	35.83	256.34	220.51
Organ. Bound	713.3	884.23	170.93	26.17	404.42	97.01	-307.41
Carbonate	120.13	57.1	-63.03		51.19	24.98	-26.21
Oxide	60.07	26.97	-33.1		25.6	10.24	-15.36
Residual	24.4	82.24	57.84	8.86	11.52	23.4	11.88
Total	974.21	1531.21	557	100.00	532.4	543.82	11.42
Total Adj.			653.12				360.39
							100

NOTE: Percent Removal determined from comparison of substrate metal fraction concentrations (mg/Kg) before and after exposure to AMD.
Adjusted Total is sum of only positive values.

Table D.1. Substrate Metal Removal By Sorbed And Solid Fractions.

ALUMINUM	G.W. Mushroom				U.F. Mushroom			
	Before	After	Removed	% Total	Before	After	Removed	% Total
	16.89	67.26	50.37	0.31	7.51	106	98.49	0.42
	49.15	154.96	105.81	0.64	15.02	138.95	123.93	0.52
	281.07	6876.98	6595.91	40.03	232.76	10029.19	9796.43	41.35
	371.69	8313.23	7941.54	48.19	230.88	12165.66	11934.78	50.38
	122.87	1335.46	1212.59	7.36	37.54	1136.99	1099.45	4.64
	685.01	1257.43	572.42	3.47	178.32	815.28	636.96	2.69
	1526.68	18005.32	16478.64	100	702.03	24392.07	23690.04	100
			16478.64				23690.04	
IRON	15.36	64.51	49.15	0.30	9.39	98.93	89.54	0.43
	98.3	206.62	108.32	0.65	15.02	283.91	268.89	1.30
	552.92	3562.04	3009.12	18.18	337.88	7769.73	7431.85	36.04
	675.8	9012.06	8336.26	50.37	382.93	9615.74	9232.81	44.77
	1400.74	5703.72	4302.98	26.00	360.4	3684.02	3323.62	16.12
	571.35	1314.56	743.21	4.49	180.2	454.86	274.66	1.33
	3314.47	19863.51	16549.04	100	1285.82	21907.19	20621.37	100
			16549.04				20621.37	

MANGANESE

G.W. Mushroom				U.F. Mushroom			
Before	After	Removed	% Total	Before	After	Removed	% Total
1.54	7.26	5.72	39.43	9.39	9.74	0.35	33.81
18.43	23.06	4.63	31.86	22.53	23.22	0.69	66.2
110.58	69.77	-40.81		82.59	64.67	-17.92	
141.3	71.6	-69.7		255.29	237.37	-17.92	
18.43	11.6	-6.83		15.02	14.44	-0.58	
21.5	25.67	4.17	28.72	9.39	9.03	-0.36	
311.78	208.96	-102.82	100.01	394.21	358.47	-35.74	100.01
		14.52				1.05	
1.54	55.43	53.89	10.38	5.63	18.15	12.52	1.54
18.43	189.32	170.89	32.92	22.53	145.17	122.64	15.07
104.44	235.74	131.3	25.30	165.18	339.92	174.74	21.47
24.57	105.96	81.39	15.68	37.54	267.61	230.07	28.27
18.43	30.95	12.52	2.41	22.53	71.65	49.12	6.04
6.14	75.21	69.07	13.31	7.51	232.15	224.64	27.61
173.55	692.61	519.06	100	260.92	1074.65	813.73	100
		519.06				813.73	

ZINC

Table D.1. Substrate Metal Removal By Sorbed And Solid Fractions.

ALUMINUM	Peaco Peat				Farmer's Peat			
	Before	After	Removed	% Total	Before	After	Removed	% Total
IRON	13.14	246.98	233.84	2.90	73.21	209.72	136.51	8.41
	105.12	1023.57	918.45	11.41	346.09	1833.32	1487.23	91.59
	1305.59	7934.12	6628.53	82.33	22460.1	16280.93	-6179.17	
	550.66	796.17	245.51	3.05	2573.46	1922.04	-651.42	
	191.12	216.07	24.95	0.31	665.55	471.96	-193.59	
	888.71	706.09	-182.62		2369.36	2022.57	-346.79	
	3054.34	10923	7868.66	100	28487.77	22740.54	-5747.23	100
			8051.28				1623.74	
	5.97	74.28	68.31	1.22	8.87	55.88	47.01	9.38
	9.56	3187.78	3178.22	56.58	8.87	152.73	143.86	28.72
	817.04	3178.78	2361.74	42.21	2271.74	2514.78	243.04	48.51
	1591.78	1415.74	-176.04		550.19	520.4	-29.79	
	683.25	673.33	-9.92		630.05	645.52	15.47	3.09
	258.01	188.82	-69.19		310.59	362.19	51.6	10.3
	3365.61	8718.73	5353.12	100.01	3780.31	4251.5	471.19	100
			5617.28				500.96	

NOTE:Percent Removal determined from comparison of substrate metal fraction concentrations (mg/Kg) before and after exposure to AMD.
Adjusted Total is sum of only positive values.

MANGANESE

	Peaco Peat				Farmer's Peat			
	Before	After	Removed	% Total	Before	After	Removed	% Total
ZINC	1.19	1.19	0	0	2.22	2.22	0	
	4.78	-40.66	-45.44		53.24	-27.42	-80.66	
	19.11	3.58	-15.53		17.75	2.22	-15.53	
	19.11	19.11	0		2.22	2.22	0	
	4.78	1.98	-2.8		8.87	3.92	-4.95	
	2.39	2.39	0		2.22	2.22	0	
	51.36	-12.41	-63.77		86.52	-14.62	-101.14	
	1.19	38.28	37.09	10.67	2.22	14.82	12.6	14.88
	4.78	165.58	160.8	46.28	8.87	63.21	54.34	64.17
	9.56	118.45	108.89	31.34	17.75	35.5	17.75	20.96
4.78	30.79	26.01	7.49	17.75	10.33	-7.42		
9.56	16.22	6.66	1.92	44.37	16.87	-27.5		
4.78	12.79	8.01	2.31	8.87	6.52	-2.35		
	34.65	382.11	347.46	100	99.83	147.25	47.42	100.01
			347.46				84.89	

NOTE: Percent Removal determined from comparison of substrate metal fraction concentrations (mg/Kg) before and after exposure to AMD.
Adjusted Total is sum of only positive values.

Table D.2. Substrate Metal Fraction Concentrations (mg/Kg) By Depth.

COLUMN	SUBSTRATE ^a	DEPTH ^b	ALSOL ^c	ALEXCH ^d	ALORGE ^e	ALCARB ^f	ALOXID ^g	ALRESH ^h
1	EKO CONT	0	4	44	653	194	92	688
1	EKO	80	15	200	5804	1596	224	797
1	EKO	50	22	316	7776	784	216	710
1	EKO	33	18	272	3648	362	168	598
1	EKO	19	32	260	2586	289	132	447
1	EKO	10	84	354	1911	234	96	439
2	GROCO CONT	0	18	96	3049	428	184	584
2	GROCO	80	11	172	2956	6676	332	605
2	GROCO	50	7	56	3374	5928	292	614
2	GROCO	33	101	308	3261	5536	356	632
2	GROCO	19	60	200	1375	229	100	356
2	GROCO	10	114	288	1379	247	112	398
3	G WST CONT	0	11	32	183	242	80	446
3	GRT WEST	80	4	28	288	380	100	603
3	GRT WEST	50	11	36	3062	3582	452	733
3	GRT WEST	33	4	24	5760	8752	1212	909
3	GRT WEST	19	85	232	9556	13744	3060	1098
3	GRT WEST	10	171	300	7328	5104	484	945
4	UFOOD CONT	0	4	8	124	123	20	95
4	UNTD FOOD	80	1	60	2011	1262	180	282
4	UNTD FOOD	50	4	12	4221	6904	600	376
4	UNTD FOOD	33	109	68	6196	13904	1264	576
4	UNTD FOOD	19	120	144	8308	10992	916	707
4	UNTD FOOD	10	116	152	8704	980	216	366
5	PPEAT CONT	0	11	88	1093	461	160	744
5	PEACO PEAT	80	478	1272	10500	1012	256	667
5	PEACO PEAT	50	138	1128	7224	703	216	640
5	PEACO PEAT	33	55	312	3936	484	128	558
5	PEACO PEAT	19	110	544	5272	503	136	500
5	PEACO PEAT	10	189	664	4256	446	108	509
6	FPEAT CONT	0	33	156	10124	1160	300	1068
6	FARM PEAT	80	93	884	8540	1121	212	1051
6	FARM PEAT	50	61	684	7820	898	200	987
6	FARM PEAT	33	69	800	7320	710	268	847
6	FARM PEAT	19	120	912	7520	723	204	884
6	FARM PEAT	10	164	952	4600	740	180	673

COLUMN	SUBSTRATE	DEPTH	FESOL	FEEXCH	FEORG	FECARB	FEOXID	FERES
1	EKO CONT	0	4	72	1008	780	1144	536
1	EKO	80	3	56	584	508	716	620
1	EKO	50	3	52	384	300	740	548
1	EKO	33	5	80	380	308	844	464
1	EKO	19	14	124	516	392	796	340
1	EKO	10	99	232	3552	840	1304	480
2	GROCO CONT	0	17	72	3072	940	936	604
2	GROCO	80	11	72	540	896	512	588
2	GROCO	50	3	76	1472	2480	1232	720
2	GROCO	33	34	124	572	708	584	552
2	GROCO	19	47	200	936	468	632	328
2	GROCO	10	158	256	8480	1600	1060	464
3	G WST CONT	0	10	64	360	440	912	372
3	GRT WEST	80	2	4	784	724	604	644
3	GRT WEST	50	4	12	2876	8480	2400	880
3	GRT WEST	33	1	8	3656	13760	12880	1124
3	GRT WEST	19	133	508	1364	2812	1108	820
3	GRT WEST	10	138	372	2844	2244	2212	844
4	UFOOD CONT	0	5	8	180	204	192	96
4	UNTD FOOD	80	3	60	4616	5280	868	164
4	UNTD FOOD	50	2	1	3776	8560	4600	392
4	UNTD FOOD	33	113	200	2104	4680	1252	268
4	UNTD FOOD	19	84	324	1956	2672	540	160
4	UNTD FOOD	10	119	348	8280	1396	920	132
5	PPEAT CONT	0	5	8	684	848	572	216
5	PEACO PEAT	80	21	80	524	436	372	164
5	PEACO PEAT	50	13	92	400	308	320	160
5	PEACO PEAT	33	15	124	1280	624	464	156
5	PEACO PEAT	19	36	160	2220	836	552	116
5	PEACO PEAT	10	286	264	11800	1756	1400	184
6	FPEAT CONT	0	4	4	1024	248	284	140
6	FARM PEAT	80	8	36	596	240	332	168
6	FARM PEAT	50	6	32	584	188	200	180
6	FARM PEAT	33	6	32	524	144	212	168
6	FARM PEAT	19	15	60	640	156	200	160
6	FARM PEAT	10	115	232	4012	480	560	124

COLUMN	SUBSTRATE	DEPTH	ZNSOL	ZNEXCH	ZNORG	ZNCARB	ZNOXID	ZNRES
1	EKO CONT	0	6	24	380	64	32	13
1	EKO	80	16	160	120	20	12	20
1	EKO	50	80	316	276	56	20	80
1	EKO	33	37	304	268	32	16	47
1	EKO	19	27	212	208	24	12	39
1	EKO	10	10	32	12	4	8	15
2	GROCO CONT	0	3	28	316	40	20	9
2	GROCO	80	120	224	52	16	8	15
2	GROCO	50	56	332	188	40	8	24
2	GROCO	33	250	200	40	20	8	25
2	GROCO	19	52	88	16	4	8	15
2	GROCO	10	35	28	4	1	8	8
3	G WST CONT	0	1	12	68	16	12	4
3	GRT WEST	80	1	4	64	12	8	5
3	GRT WEST	50	1	4	52	20	8	6
3	GRT WEST	33	1	4	44	32	8	7
3	GRT WEST	19	88	452	416	260	88	279
3	GRT WEST	10	146	368	368	120	16	43
4	UFOOD CONT	0	3	12	88	20	12	4
4	UNTD FOOD	80	1	84	84	28	12	8
4	UNTD FOOD	50	1	20	80	44	8	12
4	UNTD FOOD	33	4	40	104	72	20	36
4	UNTD FOOD	19	19	120	520	712	188	688
4	UNTD FOOD	10	36	176	304	84	24	114
5	PPEAT CONT	0	1	4	8	4	8	4
5	PEACO PEAT	80	86	228	172	64	16	27
5	PEACO PEAT	50	27	204	148	12	12	6
5	PEACO PEAT	33	4	48	40	16	8	3
5	PEACO PEAT	19	9	64	36	4	8	12
5	PEACO PEAT	10	14	60	28	24	24	3
6	FPEAT CONT	0	1	4	8	8	20	4
6	FARM PEAT	80	4	20	16	4	8	2
6	FARM PEAT	50	4	24	16	8	4	2
6	FARM PEAT	33	8	44	20	4	12	4
6	FARM PEAT	19	10	32	20	4	8	5
6	FARM PEAT	10	11	28	8	1	8	3

COLUMN	SUBSTRATE	DEPTH	MNSOL		MNEXCH i		MNORG i		MNCARB i		MNOXID i		MNRES i	
1	EKO CONT	0	6	B	16		180	B	80	B	12		13	
1	EKO	80	1	B	8		1	B	1	B	4		11	
1	EKO	50	2		8		1	B	1	B	4		9	
1	EKO	33	1	B	8		4		1	B	1	B	9	
1	EKO	19	1	B	8		1	B	1	B	4		6	
1	EKO	10	2		8		4		1	B	4		7	
2	GROCO CONT	0	4		24		144		136		56		8	
2	GROCO	80	4		8		4		4		4		7	
2	GROCO	50	14		36		16		20		4		8	
2	GROCO	33	2		4		1	B	1	B	1	B	7	
2	GROCO	19	2		8		1	B	1	B	1	B	4	
2	GROCO	10	13		8		1	B	1	B	4		6	
3	G WST CONT	0	1	B	12		72		92		12		14	
3	GRT WEST	80	2		20		64		112		8		18	
3	GRT WEST	50	10		16		80		44		8		15	
3	GRT WEST	33	2		12		40		36		12		18	
3	GRT WEST	19	3		12		1	B	4		4		16	
3	GRT WEST	10	4		12		1	B	4		4		17	
4	UFOOD CONT	0	5		12		44		136		8		5	
4	UNTD FOOD	80	21		40		72		72		4		9	
4	UNTD FOOD	50	2		8		12		28		4		10	
4	UNTD FOOD	33	3		8		1	B	8		4		8	
4	UNTD FOOD	19	2		8		1	B	4		8		7	
4	UNTD FOOD	10	2		8		1	B	1	B	4		6	
5	PPEAT CONT	0	1	B	4		16		16		4		2	
5	PEACO PEAT	80	1	B	1	B	1	B	1	B	4		2	
5	PEACO PEAT	50	1		4		1	B	1	B	4		2	
5	PEACO PEAT	33	1		8		1	B	1	B	4		2	
5	PEACO PEAT	19	2		8		1	B	1	B	4		1	B
5	PEACO PEAT	10	2		4		1	B	1	B	1	B	1	
6	FPEAT CONT	0	1	B	24		8		1	B	4		1	
6	FARM PEAT	80	1		4		1	B	1	B	4		1	
6	FARM PEAT	50	1		4		1	B	1	B	1	B	1	B
6	FARM PEAT	33	1		4		1	B	1	B	4		1	
6	FARM PEAT	19	1		4		1	B	1	B	1	B	1	
6	FARM PEAT	10	1		1	B	1	B	1	B	4		1	B

NOTES:

- CONT = control sample prior to exposure to AMD.
- Depth in cm from base of substrate.
- SOL = soluble fraction
- EXCH = exchangeable fraction
- ORG = organically-bound fraction
- CARB = carbonate (Fe, Mn and Zn) or carbonate/sulfate fraction (Al).
- OXID = hydroxyoxide fraction.
- RES = residual fraction.
- Value reported at detection limit.

Table D.3. Total metal influent loading rate for each substrate.

Substrate	Al	Fe	Mn	Zn
	----- mg -----			
Eko-Compost	13016	13953	29	418
Groco	11252	11885	21	350
Great Western Mushroom Compost	10984	11416	21	334
United Foods Mushroom Compost	11816	11841	25	342
Peaco Peat	11085	11625	23	304
Farmers Peat	9694	9607	21	262

note: values determined by summing product of volume AMD (l) in each influent cycle and the concentration (mg/l) of a given metal in that cycle.

APPENDIX E

SUBSTRATE METALS

FRACTIONATION METHODS

SEQUENTIAL EXTRACTION OF WETLAND SUBSTRATES FOR THE QUANTITATIVE DETERMINATION OF METAL FRACTIONS

COPY

used in the laboratory of R.K. Wieder, Villanova University

Day 1

1. Weigh 1.25 g of freeze-dried and ground peat or 2.5 g of freeze-dried and ground sawdust, straw/manure, or mushroom compost into a 50 mL centrifuge tube (we use plastic disposable tubes)
2. Add 40 mL DDW to the sample in the centrifuge tube, cap the tube, and shake in a shaker for 30 min
3. Centrifuge at 2000 rpm for 10 min
4. Pour off the supernatant and filter through Whatman 541 filter paper into a 100 mL volumetric flask
5. Add 25 mL DDW to the centrifuge tube, thoroughly mix, and centrifuge, pour off supernatant, and filter through the same filter paper into the same 100 mL volumetric flask in step 4
6. Repeat step 5
7. Bring the contents of the 100 mL volumetric flask to volume and store for subsequent metal analysis (*Water-soluble Fe, Mn, Al, Ca, Mg*)
8. Add 40 mL of 1 M KNO_3 to the centrifuge tube and shake overnight in a shaker

Day 2

1. Centrifuge at 2000 rpm for 10 min
2. Decant, filter, and rinse twice as described in Steps 4-6, Day 1, above
3. Bring the contents of the 100 mL volumetric flask to volume and store for subsequent metal analysis (*Exchangeable Fe, Mn, Al, Ca, Mg*)
4. Add 40 mL of 0.1 M $\text{Na}_4\text{P}_2\text{O}_7$ to the centrifuge tube and shake overnight in a shaker

Day 3

1. Centrifuge at 2000 rpm for 10 min
2. Decant, filter, and rinse twice as described in Steps 4-6, Day 1, above
3. Bring the contents of the 100 mL volumetric flask to volume and store for subsequent metal analysis (*Organically bound Fe, Mn, Al, Ca, Mg*)
4. Add 40 mL of 0.1 M EDTA, adjusted to pH 7 with NaOH to the centrifuge tube and shake overnight in a shaker

Day 4

1. Centrifuge at 2000 rpm for 10 min
2. Decant, filter, and rinse twice as described in Steps 4-6, Day 1, above
3. Bring the contents of the 100 mL volumetric flask to volume and store for subsequent metal analysis (*Carbonate Fe, Mn, Al, Ca, Mg*)
4. Add 30 mL of 0.3 M $\text{Na}_3\text{C}_6\text{H}_5\text{O}_7 \cdot 2\text{H}_2\text{O}$ (sodium citrate) and 3.75 mL of 1 M NaHCO_3 (sodium bicarbonate)

to the centrifuge tube and place in an 80°C water bath in a hood
5. Add 0.75 g of $\text{Na}_2\text{S}_2\text{O}_4$ (solid) to the centrifuge tube in the water bath and stir constantly with a glass rod for 1 min. Continue heating for 30 min, stirring occasionally (Note: this step really smells, so a hood is essential)
6. Centrifuge at 2000 rpm for 10 min
7. Decant, filter, and rinse twice as described in Steps 4-6, Day 1, above
8. Bring the contents of the 100 mL volumetric flask to volume and store for subsequent metal analysis (*Oxide or oxide bound Fe, Mn, Al, Ca, Mg*)
9. Add 40 mL conc. HNO_3 , mix gently, lightly cap, and let stand overnight (this reaction may be somewhat violent, producing considerable gas; therefore, do not cap tightly and do not shake the tubes)

Day 5

1. Centrifuge at 2000 rpm for 10 min
2. Decant, filter, and rinse twice as described in Steps 4-6, Day 1, above
3. Bring the contents of the 100 mL volumetric flask to volume and store for subsequent metal analysis (*Residual Fe, Mn, Al, Ca, Mg*)
4. Discard centrifuge tube and remaining substrate residue

Procedure modified from: Miller, W.P., W.W. McFee, and J.M. Kelly 1983. Mobility and retention of heavy metals in sandy soils. *Journal of Environmental Quality* 12: 579-584.

